A TREATISE

ON

EXPLOSIVE COMPOUNDS,

MACHINE ROCK DRILLS

AND

BLASTING.

BY

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PREFACE.

SOME years ago the author of this work was engaged as Resident Engineer in the construction of a Tunnel, begun about the time that Machine Rock Drills had been successfully introduced in the United States. Machine Drills were, however, in many respects still in their experimental stage, and the same thing may be said of the higher Explosives—Gun-cotton, the Compounds of Nitro-Glycerine, etc., etc., which since have come into such universal use. Naturally the experience gained in the construction of a large Tunnel, driven partly through very hard rock, by the aid of these new agents, related to many new points, and opened a wide field for experiment and practical study. The interest which at the time the author took as a professional duty in his work, continued after the completion of the Tunnel in question, and incited him to make a study of the comparative merits of the Rock Drills and of the Explosive Compounds in the Market, as to which he could obtain general data, and moreover, to seek and set forth, so far as lay in his power, the principles of Blasting, of which the art is, of course, as susceptible as is any other, of intelligent scientific direction, though heretofore generally left to rule-of-thumb guidance.

The results reached were published in the author's work on Tunneling, etc., first issued in 1878, and recently republished in an enlarged edition.

The Treatise on Tunneling, being devoted mainly to a study of the principles of Tunneling proper, included a large amount of matter, not directly pertinent to the object of this volume, the subjects of Explosive Compounds, of Rock Drills, and of Blasting being treated in certain Chapters of the work on Tunneling, which were especially devoted to those matters.

The kindly reception which had been given by the profession to the author's work on Tunneling, caused the first edition to be exhausted within three years; and in issuing the second edition, the author carefully revised the work, and added such new matter as was needed to make the several parts complete to date, the changes being made almost exclusively in the Chapters relating to Explosive Compounds, Air Compressors, and Machine Rock Drills; the fact being, that the exhaustion of the first edition rendered a second necessary before the actual progress in the Art of Tunneling proper, had demanded it.

Since the year 1878 much has been learned in the Art of Blasting, relative to Explosive Compounds and Modern Machine Drills, so that the changes and additions in the author's work on Tunneling added over one hundred pages to the Chapters relating to those subjects. In the present volume those changes and additions are all included, enabling the owners of the first edition of the Work on Tunneling, who may not care to subscribe for the second edition, to obtain in this volume nearly all the additional matter embodied in the second edition. This work is, in fact, mainly a rescript of those portions of the author's larger work, which are devoted to Explosive Compounds, Rock Drills, and Blasting; and it is hoped that this volume

may be of service to students of engineering, and to engineers who desire to study those subjects without going into that fuller consideration of the principles of Tunneli g proper, which is necessary to the engineer or contractor actually engaged in Tunnel construction.

There is at the present time no full work in English on the subjects here treated, though many valuable Monographs and Papers, especially on Explosive Compounds, and on the phenomena attendant on Explosion and Detonation, have appeared within the last decade in Pamphlet form, and in the papers read before the Engineering Societies in England and in America.

It is the hope of the author that this work may be found in some measure to supply the want of a general Treatise upon questions heretofore studied and discussed only in detached and separate form. If but a beginning in this direction has been made, such beginning may at least serve as an Index for the future study and elaboration of others.

PHILADELPHIA, January 1st, 1883.

TABLE OF CONTENTS.

CHAPTER I.

A History of Rock Excavation, Tunneling, and Blasting from the Reign of Rameses II. to the Present Time.

The perseverance that the ancients showed in excavating their tunnels is astonishing when we consider that their means of excavation were limited to hand tools, wedging, etc., supplemented occasionally, perhaps, by the use of the "fire-setting" system of excavation, which simply consisted in heating the rock and suddenly cooling it with water, and so disintegrating it. Diodorus, in an account of mining operations in Ancient Egypt and Ethiopia, speaks of the fire-setting system being employed, and gives a frightful picture of the sufferings of the slaves and captives condemned to toil in the mines. Pliny also mentions the fire-setting system, and, according to Livy, Hannibal used it in crossing the Alps, when he is said to have cooled the rocks with vinegar after heating them.

This use of fire under ground, of course, gave a fearfully vitiated atmosphere. The only device of which we have any record as being used by the ancients to improve the ventilation, consisted in waving large sheets of cloth over the mouths of the shaft and slope-openings. These, acting as fans, agitated the air, and afforded some slight relief.

In the middle ages, the fire-setting system was employed both in warfare and in mining. Figs. 1 and 2 are from Agricola's "de Re Metallica," Basel, 1556,* and show devices used at that time in Germany for improving the ventilation. In Fig. 1, the wind blows against the frame D D, and is deflected down the shaft. In Fig. 2, the wind is allowed to blow into the cask A, through the opening C, whence it passes down through the pipe D. The rudder H served to keep the opening in the barrel facing toward the wind. At the present day, the "fire-setting" system is still used in the Rammelsberg at Goslar, at Felsöbanya in Siebenbürgen, and in some mining regions in Russia, Norway, and Sweden.†

Also, Professor H. S. Munroe tells us that the system is to-day in extensive use in Japan for driving long mining tunnels. In Europe, it seems now only to be applied in the case of very hard rock, and where free ventilation is attainable, but rarely in mining sulphurous or arsenious ores, on account of the vapors generated by the partial roasting effected; though Löhneyss tells us, in his "Bericht vom Bergkwerck" (1617), that in those days the miners suffered greatly from the vapors; also, that in the mines of St. Georg, silver is actually said to have flowed in liquid form from the veins on account of the heat. Figs. 3 and 4 are also from Agricola, and show the fire system as practiced in Germany at that time.

There has been an attempt lately made by Hugon,‡ at the Challanges Mines in France, to apply fire to rock excavation; he constructed a large furnace on wheels, so arranged that a

* From a copy in Library of Eckley B. Coxe, Drifton, Pa.

† See L. Simonin's "Underground Life," translated by H. W. Bristow, p. 410.

‡ "Leitfaden zur Bergbaukunde," von Dr. Albert Serlo. Berlin, 1878.

strong draught should pass out at the front, and thus throw the flame directly against the rock face.

In the few localities where the old fire system is now used, it is chiefly applied to enlarg-

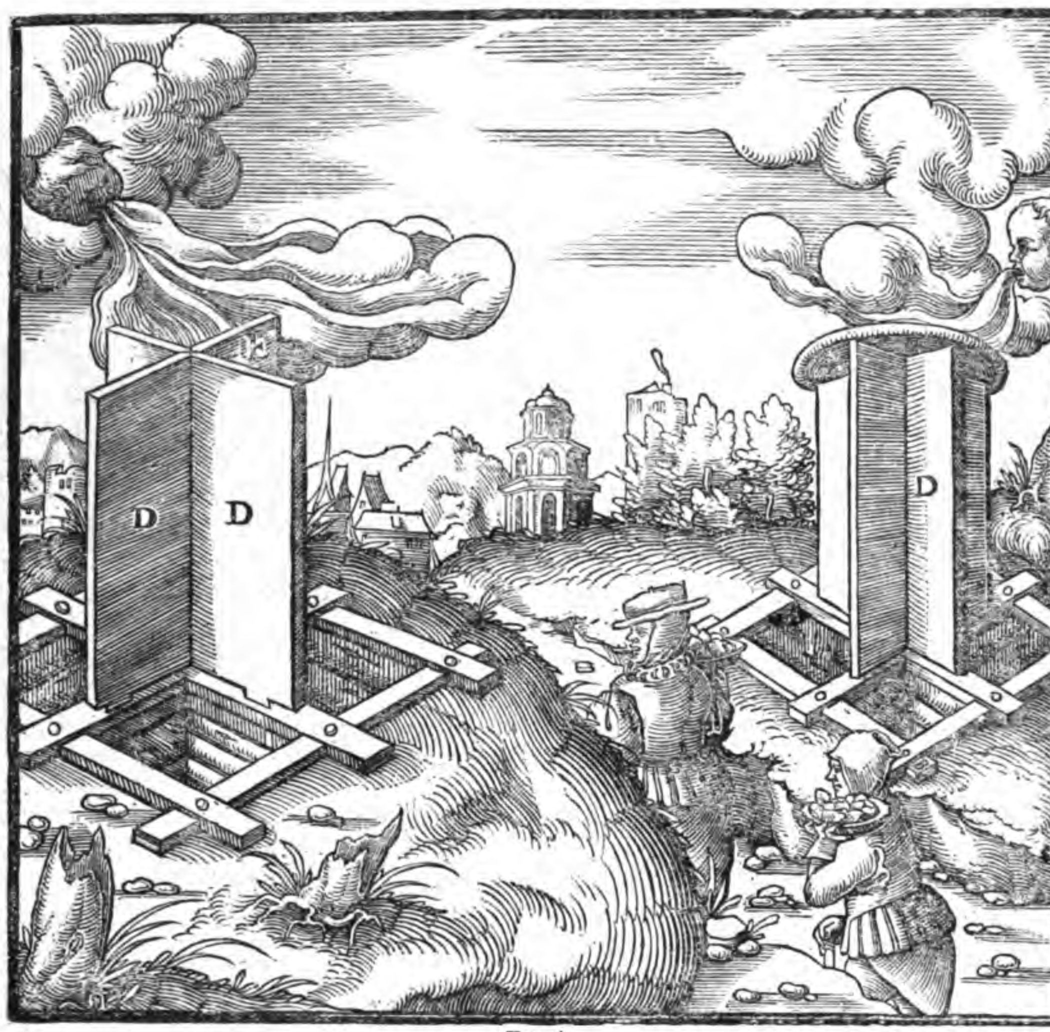


FIG. 1.

PRIMITIVE VENTILATING APPARATUS.

(From Agricola's "de Re Metallica," 1st ed., Basel, 1556.)

ing a drift or chamber in very hard rock, especially in cases where it is desired to bring down the roof; and the question has been mooted whether, in some exceptionally rare cases of large tunnels driven with a bottom heading in hard rock, requiring no timbering, the fire system might not profitably be used in enlarging; there would remain, however the question—even supposing the system to be a practicable one—whether there would not be great risk of shattering, and so rendering dangerous to an uncertain depth, a roof which by ordinary driving would be perfectly safe.

It has been surmised that the use of the diamond for rock-boring and cutting was known to the ancients, and that M. Leschot's laurels are but leaves gathered from a twig springing from the root buried in far distant ages. By referring to ancient writers—Pliny, Italiana Vitori, Lapidarium of Marbodus—we find that diamonds formed an important adjunct to the

"hewers of stone" as well as the lapidary. And it is thought by Eastern writers,* that diamond (shamer) pointed tools were used in the construction of Solomon's temple, where "there was neither hammer, nor axe, nor any tool of iron heard in the house while it was in building."

To go back to first principles, we must allow that the Egyptians, in this as in their many

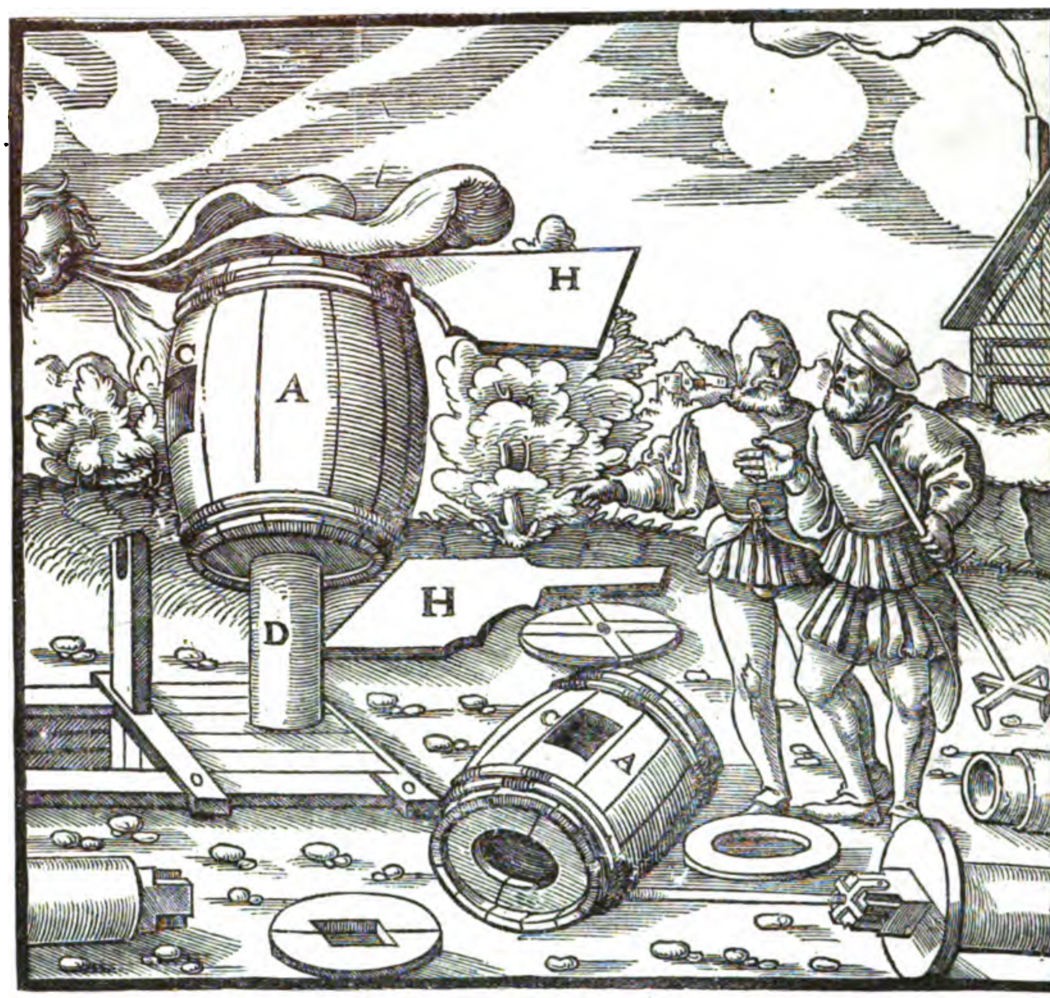


FIG. 2.

PRIMITIVE VENTILATING APPARATUS.
(From Agricola's "de Re Metallica," 1st ed., Basel, 1556.)

other arts, led the world by many centuries. How the wonderful subterranean constructions of both ancient Egypt and India were ever carried through, we would now be at a loss to conceive, did we not remember that, in both, the mass of the people were but slaves, subjected to the despotic will of the few. Moreover, the strong religious fanaticism of the masses, and the unlimited power possessed by their monarchs, enabled the latter to construct works, still existing in fact or record, marvelous in their magnitude and grandeur: the grottos of Samoùn and of the crocodiles in Upper Egypt,† not far from Monfalout; the caverns of Thebes, amounting in the aggregate to over fifteen leagues in length; the tombs of Memphis, situated,

* "Engineering," May 5, 1876, p. 377.

† "Les Galeries souterraines," p. 3, Max Hélène.

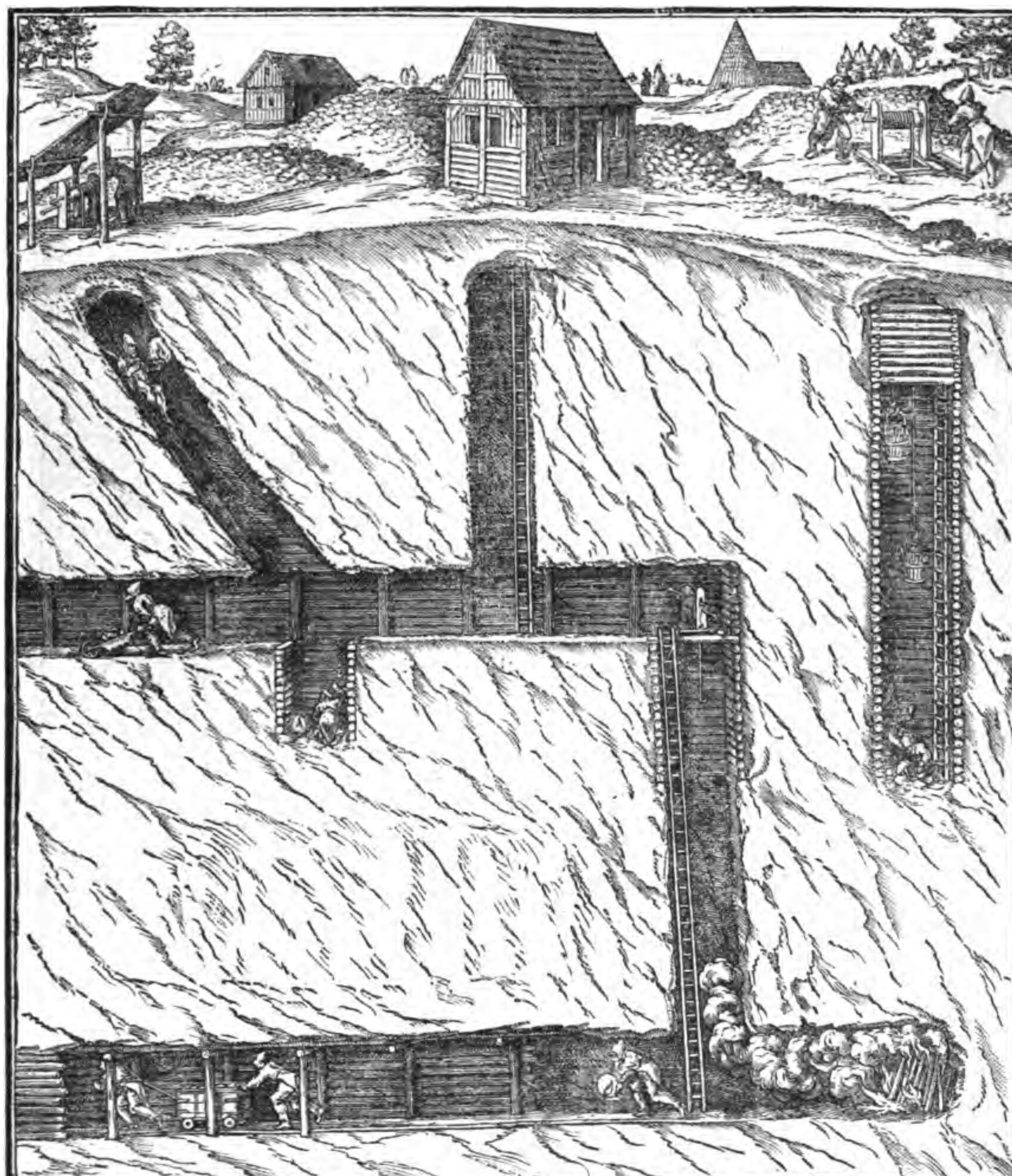


FIG. 3.

THE FIRE-SETTING SYSTEM OF EXCAVATION.

(From Agricola's "Bergwerck Buch" (3d ed. of "de Re Metallica"), Basel, 1621).

many of them, more than twenty-five yards below the surface of the ground; and the catacombs of Alexandria.

Both in Egypt proper and in Nubia, the Egyptians were in the habit of excavating monu-

Fig. 4.

THE FIRE-SETTING SYSTEM OF EXCAVATION.
(From Agricola's "de Re Metallica," 1st ed., Basel, 1556.)

ments from the living rock,* but with this curious distinction: with scarcely an exception, all the excavations in Egypt proper are tombs, and no important example of a rock-cut temple has yet been discovered; in Nubia, on the other hand, all the excavations are temples, and no tombs of importance are to be found anywhere. Like all rock-cut temples, these Nubian ones are copies of structural buildings, only more or less modified to suit the exigencies of their situation—a situation that did not admit of very great development inside, as light and air could only be introduced from the one opening of the doorway.

The principal examples of this class of monuments are the two at Ipsamboul, the largest of which is the finest of its class known to exist anywhere. Its total depth from the

* Fergusson's "History of Architecture," p. 112.

face of the rock is 150 feet, divided into two large halls and three cells, the whole connected by passages. Externally, the façade is about 100 feet high, and is adorned by four of the most magnificent colossi in Egypt, each 70 feet in height, cut out of the solid rock, and representing King Rameses II., who caused the excavation to be made. Fig. 5 shows a longitudinal section of this hall.

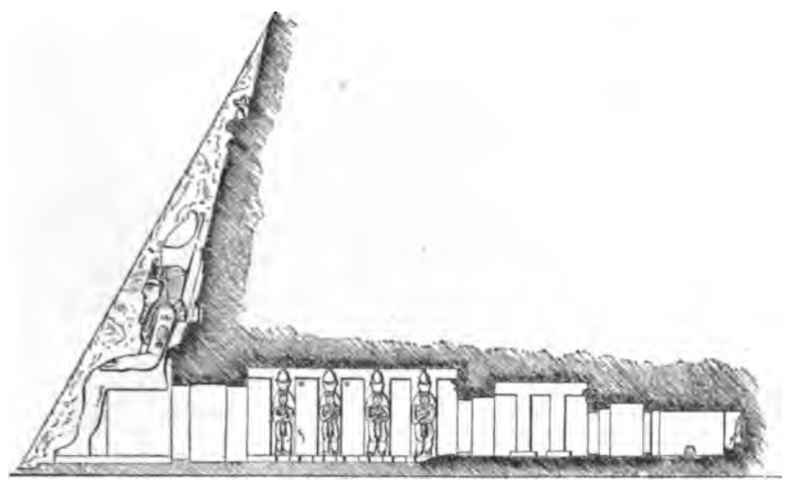


FIG. 5.
Section of Rock-cut Temple at Ipsamboul. Scale 50' = 1".

Besides the above, there is a very beautiful though small example at Kalabsche, likewise belonging to the age of Rameses II.; there are, moreover, smaller temples at Derri and Balagne. At Essabua, Girsheh, and Dandour, the cells of the temple have been excavated from the rock, but their courts and propylons are structural buildings added in front. This last arrangement is found also as a characteristic of the temples of Gibel Barkal, in the kingdom of Meroe, showing how far the rock-cutting practice prevailed in the upper valley of the Nile.

As all these temples are contemporary with the great structures in Egypt, it seems strange that the eternity of a rock-cut example did not recommend this form of temple to the attention of the Egyptians themselves. But, with the exception of a small grotto called the Speos Artemidos, near Beni Hassan, and two small caves at Silsilis, the Egyptians seem never to have attempted it, trusting apparently to the solidity of their masonic structures for that eternity of duration to which they aspired. It is said by Fergusson that every circumstance seems to point to the fact, that, if there was any connection between Africa and India, it was with the provinces in the upper part of the valley of the Nile, and not with Egypt proper. This distinction is of great interest, for now, on turning to the history of rock excavation in India, we shall see that the rock-cut temples there are the finest examples of subterranean excavation that the world has ever known.

The Hindu * caves and rock-cut temples are not as ancient as those of Egypt, the oldest dating back only to between the second and third centuries B.C., whereas the Ipsamboul Temple, above described, is said to date back as far as 1500 B.C., or to the reign of Rameses II.

These Hindu caves occur in groups, the number in a group in some cases reaching as high as 100 distinct excavations. It has been estimated that, in all, there are not less than 1000 of them, of which 100 may be of Brahminical or Jaina origin, and the remainder Buddhist; the large majority of the latter being used as monasteries. Nine tenths of the caves now known are within the confines of the Bombay Presidency; owing probably to the fact that the rock in that locality is especially adapted to the work, being composed of various trap formations of uniform texture, and occurring in abrupt perpendicular cliffs, with few flaws or faults in the rock. The earliest work seems to have been done about 543 B.C., in

* See Fergusson's "Illustrations of the Rock-cut Temples of India," and his "History of Indian and Eastern Architecture." Also General Cunningham's "Archæological Reports;" and "Monuments Anciens et Modernes," par Jules Gailhabaud.

improving the Satapanni Cave in the Behar group in Bengal; this, however, was simply a natural cave embellished with ornamentation.

The earliest cavern known is the Sudama or Nigope Cave, cut in the twelfth year of the

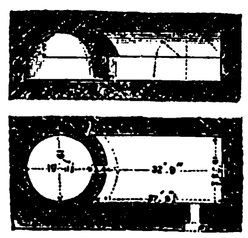


FIG. 6 (*a*).
Sudama or Nigope Cave.

FIG. 6 (*b*).
Lomas Rishi Cave.

reign of Asoka, or about 260 to 264 B.C. Its dimensions are given in Fig. 6 (*a*). Fig. 6 (*b*) shows the façade of the Lomas Rishi Cave, in the same group (built about 200 B.C.). Fig. 7 shows the façade of the cave at Bhaja, also of about this date; and it is interesting to note that in these early examples of stone-work, the columns slope inward. The reason assigned for this curious conformation is that the caves were cut in imitation of the earlier wooden-roofed temples, and the supports were thus sloped with Eastern fidelity to detail, so as to conform to the inward slope of the rafter supports of their wooden structures. Later come the caves of Nassick, about 129 B.C. It should be noted that, in all this most beautiful early tunnel-work, there is not a particle of stucco or masonry. It was all

FIG. 7.
Cave at Bhaja.

pure laborious cutting with hand tools in the hardest of rock; and, undoubtedly, except perhaps in the centre excavations of the largest caves, it would have been out of the question to risk shaking or cracking the rock by any fire-setting excavation.

The caves of Karli date about 78 B.C. Figs. 8 (*a*) and (*b*) show the ground plan and elevation of the largest one, and Fig. 8 (*c*) a view of its interior; in it we see that the early architectural defects are gone; the pillars of the nave are quite perpendicular, and in it the style of ornamentation reached a perfection never afterward surpassed in the Indian temples. The Karli caves and those of Ellora are the most magnificent in India; the latter range from 200 to 300, and some perhaps to 600 A.D., and their passages and excavations amount in all to over two leagues of underground work, a pretty strong example of primitive tunneling, executed by men who, though they perhaps knew of gunpowder, certainly seem never to have applied it to blasting, and to whom dynamite was not even a visionary suggestion of the distant future. Later came the caves of Salsette (about 500 A.D.), and those of Elephanta (about 800 A.D.), both on islands near Bombay. Still later (about 1400 A.D.), the Gwalior caves were excavated; these were among the latest cut, and are located further north than any of those previously cited.

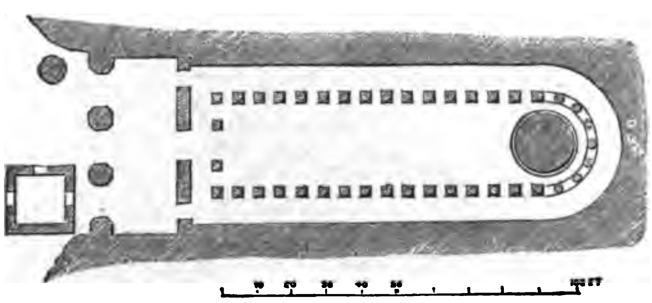
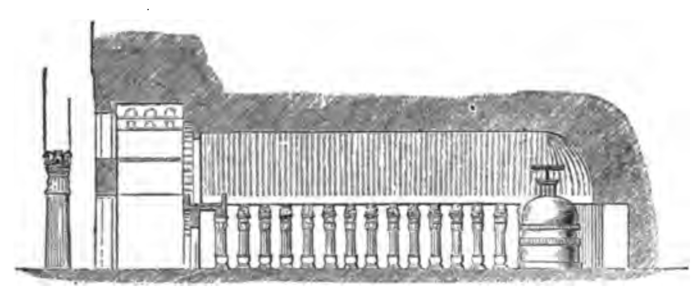


FIG. 8 (*a*).

Plan of Cave at Karli.



Section of Cave at Karli. Scale 50 ft. to 1 in.

FIG. 8 (*b*).

Among the very famous open-air rock-cut temples of India should be mentioned those of Bamian, in Afghanistan, cut in the rocky sides of a pass through the Hindoo Koosh range. These open-air temples, however, though undoubtedly rock-work, are not connected with tunneling proper. Many of them, it is said, have been defaced by the vandalism of the English. This we can readily believe; troops, for instance, who would stable their horses on the magnificent tesselated floors of Delhi, would not hesitate to deface what would appear to them the ruder structures of a so-called uncivilized race. Indeed, we are told that the barbarous civilization of the nineteenth century has actually sanctioned the construction of a railway through the Bamian Pass, in the course of which many of these beautiful temples have been destroyed.

The custom of constructing subterranean passages, to serve as places of sepulture, was, however, by no means confined to the ancient Egyptians and Hindus. The Hebrews, Scythians, Greeks, Etruscans, Romans, Carthaginians, all followed the same custom. Carthage had her catacombs, and we find them now in Asia Minor and Syria; and those of

Etruria, Sicily, Rome, Naples, Malta, and Paris show how generally this primitive tunneling

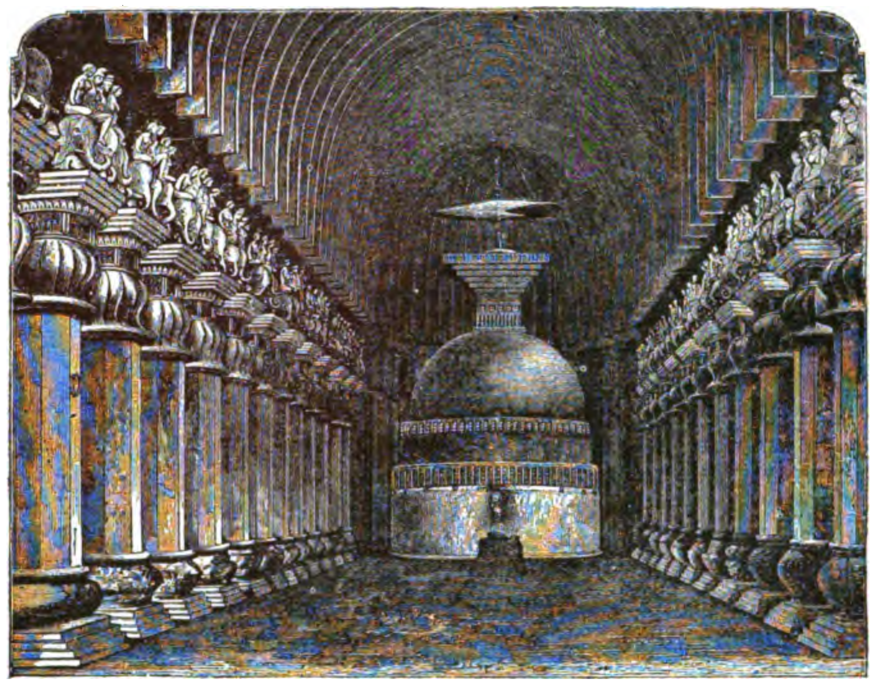


FIG. 8 (c).
View of Cave at Karli.

custom prevailed in Europe, not only from a very ancient date, but even up to and past the early Christian era. On the western continent, we find the same custom among the Aztecs and Peruvians. Indeed, we Americans have no reason to be ashamed of our ancient tunneling record, for the conduits and even rock-cut tunnels of Mexico and Peru were most remarkable.

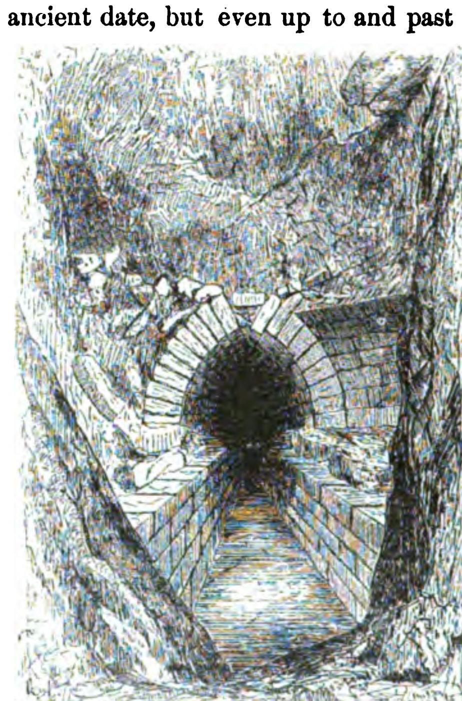


FIG. 9.
Vaulted Drain under south-east Palace of Nimroud.

Among the Assyrians and Medes, we find tunnel-work at an early date, but no subterranean system of excavation for purposes of sepulture developed on so stupendous a scale as was accomplished by the Egyptians and Hindus. Their tunnel-work was rather more practical in its bent. Fig. 9 shows a vaulted drain under the south-east palace of Nimroud.

Diodorus tells us that Semiramis caused works to be set on foot toward piercing the mountains of Baghistan and Zaracœus. At Babylon, a tunnel was actually constructed under the Euphrates. On one side of the river stood the royal palace or Seraglio, and on the other the temple of Jupiter Belos. Between these edifices there were two channels of communication, both stupendous pieces of work. The first was a bridge of five

stadia (3034·5 feet) in length, supported by strong piers. The second was an arched tunnel under the river, lined with brick, 12 feet high and 15 feet wide. Strabo fixes the width of the Euphrates at only one stadium (606·9 feet), but as it is reasonable to assume that the same allowance would be made for overflows and the lowness of banks, in the case of the tunnel as of the bridge, it may be held that they were both of nearly the same length. This tunnel, however, can scarcely be cited as an example of subaqueous work, as Herodotus tells us that the waters of the Euphrates were diverted from their bed before the construction of the bridge and tunnel was begun. In Bœotia, a tunnel of very ancient date is said to have been constructed for the drainage of Lake Copais. Herodotus mentions a tunnel in the island of Samos, cut through a mountain 150 ὀργυιᾶ (900 feet) high. Its length was seven stadia (4248 feet), and its cross-section 8 by 8 feet. The chief-engineer was Eupalinus, the son of Naustrophus, an inhabitant of Megara, and it was built during the sixth century B.C. Elaborate arrangements were often made in the ancient cities for drainage and water supply. We are told that when Cæsar arrived at Alexandria, he found the city almost hollow underneath from the numerous aqueducts. Every private dwelling had its reservoir, supplied by subterranean conduits from the Nile.

As we come down to the question of tunneling proper, the modern engineer may well pause and study the record of the Romans, though it is probable that even they learned the art of building their emissaria from the Etruscans. The Romans built tunnels for passage, tunnels for drainage, tunnels on their aqueducts, through rock and through earth, not only in Italy, but wherever their conquests led them. The remains of their great works are constantly being discovered at the present day, and the excellent preservation of the cement and masonry is a telling comment on that of some of their modern successors. The emissaria, or drainage-tunnels, first built by the Etruscans, from whom the Romans learned the art, are among the grandest engineering achievements of antiquity. In 1858, a tunnel was discovered between Lake Avernus and the ancient city of Cumes, which was probably used for the water supply of the city. Only a few years since, the French engineers engaged with the surveys for a water conduit from Tondja to Bougie in Algiers, made a very interesting and valuable discovery. A mountain which was situated in the proposed line of the conduit was to be tunnelled for a length of about 450 metres, and in searching for the most suitable place, the engineers discovered an ancient tunnel 2·15 metres in height and 0·6 metre in width. It is supposed that this is the same tunnel mentioned in an inscription found at Lambessa, according to which the tunnel was built in the reign of Antoninus Pius, the plans being proposed by a veteran of the Third Legion, named Nonius Datus. Another Roman tunnel, about 900 metres in length, that of Hagdek, near Lake Bienna, was lately discovered in Switzerland. During the construction of a canal from the River Aar to Lake Bienna, numerous shafts, from 50 to 60 metres apart, were found along its line, and it is supposed to have served as a passage for an ancient highway. Other road-tunnels were the one on the Flaminian road through the Apennines, built by Vespasian, and the passage of Pausilippo, in use at the present day, between Naples and Pozzuoli, which was built, according to Strabo, by Cocceius, about 36 B.C. Strabo gives its original length as 1000 paces, the height 30 feet, and width 25 feet. A tunnel was constructed in 359 B.C. to tap Lake Albanus, at the instance, Livy tells us, of the oracle of Delphi. It was 6000 feet (1500 paces) long, 7 to 8 feet high, and 5 feet wide. Fifty shafts were sunk on its line, and the work is said to have been finished within one year, though it was driven through the hardest lava.

As to these shafts, or *putei*, it is said,* on the authority of Frontinus, that the Romans did not use vertical shafts, but that the putei, often called shafts, were in fact slopes, up which

* Ržiha, "Eisenbahn- Unter- und Oberbau," p. 330.

the excavated material was carried. This, however, must rest on a misconception, for on the line of the Lake Fucinus Emissarium, lately cleared out by the Neapolitan Government, both shafts and slopes occur, and a visitor says of them: "The depth at which the tunnel runs underground is very great, some of the perpendicular shafts in the plain being nearly 400 English feet in depth. Other sloping shafts lead down into the canal from the sides of the mountain, and most of these shafts, and the greater part of the main watercourse, had been cleared out when I saw them." * Vitruvius speaks of tunnels in clay and sand which required arching, and gives it as his opinion that it is necessary to sink one puteus for every section of one actus (355·7 m.).

A similar work to the Lake Albanus Tunnel, but of greater magnitude, was the emissarium above referred to, which was undertaken to connect Lake Fucinus (now Celano) with the River Liris (now Garigliano); 30,000 men were employed on it for eleven years, and some twenty-two openings were sunk on the line; it was finished at a vast expense A.D. 52. Its length is given by Livy as being from 3000 to 3500 paces (4446 to 5187 m.); its height 19 feet, and width 9 feet. In the article in "Blackwood's Magazine," above referred to ("Eight Days in the Abruzzi"), there is an account of the modern clearing out of this work by the Neapolitan Government. In this article, the writer estimates the length of the tunnel to be about three miles, and, as cleared out, the height appeared to be nowhere less than 20 feet; the width was sufficient to allow two working cars to pass: where the tunnel was located through solid rock, there was no arching. An invert had been put in, in the places where needed, but it was destroyed in the course of the new excavations.

The accuracy of the surveying in these works is astonishing, when we consider the rudeness of the instruments the ancients had at their command. Among those used in leveling by the Romans, were the libra aquaria and dioptra, of which we have no clear descriptions. The chorabates seems to have been preferred. It consisted simply of a rod or plank, about 20 feet long, mounted on two legs at its extremities, of equal length. The rods or legs were secured by diagonal braces, on which were marked correctly vertical lines. A plumb-line attached at each extremity, and passing over these diagonal braces, indicated whether the instrument was level. When the wind prevented the plumb-bobs from remaining stationary, a channel in the upper edge of the horizontal rod was filled with water, and if the water touched equally both extremities, the level was supposed to be correct; and then the observation of the descent or elevation of the ground was made with accuracy.

A full work might well be devoted to a consideration of the aqueducts built by the Romans, and of the complete system of sewerage introduced in their principal cities; the sewer system of Rome being especially remarkable, where the ancient Cloaca Maxima, or great sewer, may be seen to-day in good preservation, though its utility has been impaired by the filling up of the Tiber. Among the covered aqueducts built for the water supply of Rome, Frontinus tells us in his "De Aquæductibus," were the

Aqua Julia	15,126	paces long,	6,472	paces	underground.
" Anio Vetus	43,000	" "	221	"	"
" Anio Novus	58,700	" "	49,300	"	"
" Marcia	61,710	" "	54,747	"	"
" Appia	11,190	" "	11,130	"	"
" Virgo	14,105	" "	12,865	"	"
" Claudia	46,406	" "	36,230	"	"

Wherever they went, the Romans left evidences of their great engineering skill, as may

* "Blackwood's Edinburgh Magazine," vol. xxxviii., p. 657.

be seen by the aqueducts and sewers of Nismes, Lyons, Metz, Rheims, and Jouy, in France; Evora and Lisbon, in Portugal; and the one built at Constantinople by Hadrian.

After the fall of the Western Empire, we have no marked mention of tunnel-work in any form in Europe through the dark ages, except in the subterranean passages, tombs, and crypts under castles, cloisters, monasteries, churches, etc. There were, indeed, also some adits and drifts driven in Germany in connection with the early crude attempts at mining. During the middle ages, there is a record of the construction of a drainage-tunnel from the Lake of Montady, near Béziers,* 4462 feet (1360 metres) in length,† but it was not until 1450 that the modern revival of tunnel construction on a large scale received its first impulse from Anne of Lusignan, who in that year commenced the construction of a tunnel in the Alps, between Nice and Genoa, through the Col de Tenda (height of the pass 1800 m.) The work was dropped, but subsequently, according to Kaselowski, continued by Victor Amadeus III. in 1782, but finally abandoned in 1794, in consequence of the invasion by the French: at this time, some 2500 metres of the tunnel are said to have been completed.

The introduction of gunpowder, however, gave a new zest to the search after the precious metals. The idea of using it in military operations was first broached by Pedro Novarro in 1503, in the Italian campaigns of Gonzalvo de Cordova, though mining and countermining may date back to Typhon of Alexandria. Powder was not applied in ordinary mining operations until much later, for Agricola's "de Re Metallica" (Basel, 1556, 1557 ‡ and 1621) shows that at those dates (Figs. 3 and 4) the fire system of excavation was much used. Figs. 10 and 11 show also examples of pick and gad work from Agricola. The methods of timbering drifts, however, are shown, both in Agricola's work, and also in Löhneyss's "Bericht vom Bergkwerck" (1617), to have been very much the same two hundred and fifty years ago as they are now (see Fig. 3). The only advance that has been made in modern times, in the art of timbering, has been in extending the old methods common in mining to cover the larger tunnels driven on canals and railroads. Schoen § states that, in the province of North Rumiilien (Roumania) in Turkey, near Katschanik, he found a spacious road-tunnel through gneiss, excavated by the Turks some two hundred years ago. Road-tunnels are found also in Austria, built during the last two centuries, and excavated through the solid rock.

The stupendous mining systems of Germany and England furnished a school of men who were trained to grapple with the difficulties of drifting in mining, so that on the revival of engineering in the last century, large tunnels began again to be cut through solid rock on canals, though it was not until the present century that the attempt was first successfully made (in the case of the earlier Thames Tunnel) to tunnel through soft ground. In this, the English are said to have been the first, so that their system is the legitimate outgrowth of the longest experience. They were subsequently followed by the French, Belgians, Germans, and Austrians, and we Americans have naturally derived the main features of our system of soft-ground excavation from that pursued in the mother country.

The list of the wide tunnels of modern times was first opened by Riquet, a French engineer, who, in 1679–'81, built the Malpas Tunnel, 515 feet (157 m.) long, 22 feet wide, and 27 feet high, on the Languedoc Canal. It was arched some ten years later. This tunnel is said to have been commenced in 1665, with the support of Colbert, and it was the first modern tunnel constructed for transportation, in the commercial sense of the word. A few years later, the Campmaze subterranean conduit, 416½ feet (127 m.), was built in France on an irrigation canal. There is no further record of tunneling in France until the Rive de Gier Tunnel, 551 feet (168 m.), on the Givors Canal, was built a century later, in 1770, and the

* Bulletin No. 5, 1856, Corps des Ponts et Chaussées.

† Also the Moors are said to have driven some irrigation tunnels in Spain.

‡ Ed. of 1557 was the first *in German*, and was called "Vom Bergkwerck." § "Der Tunnelbau," p. 8.

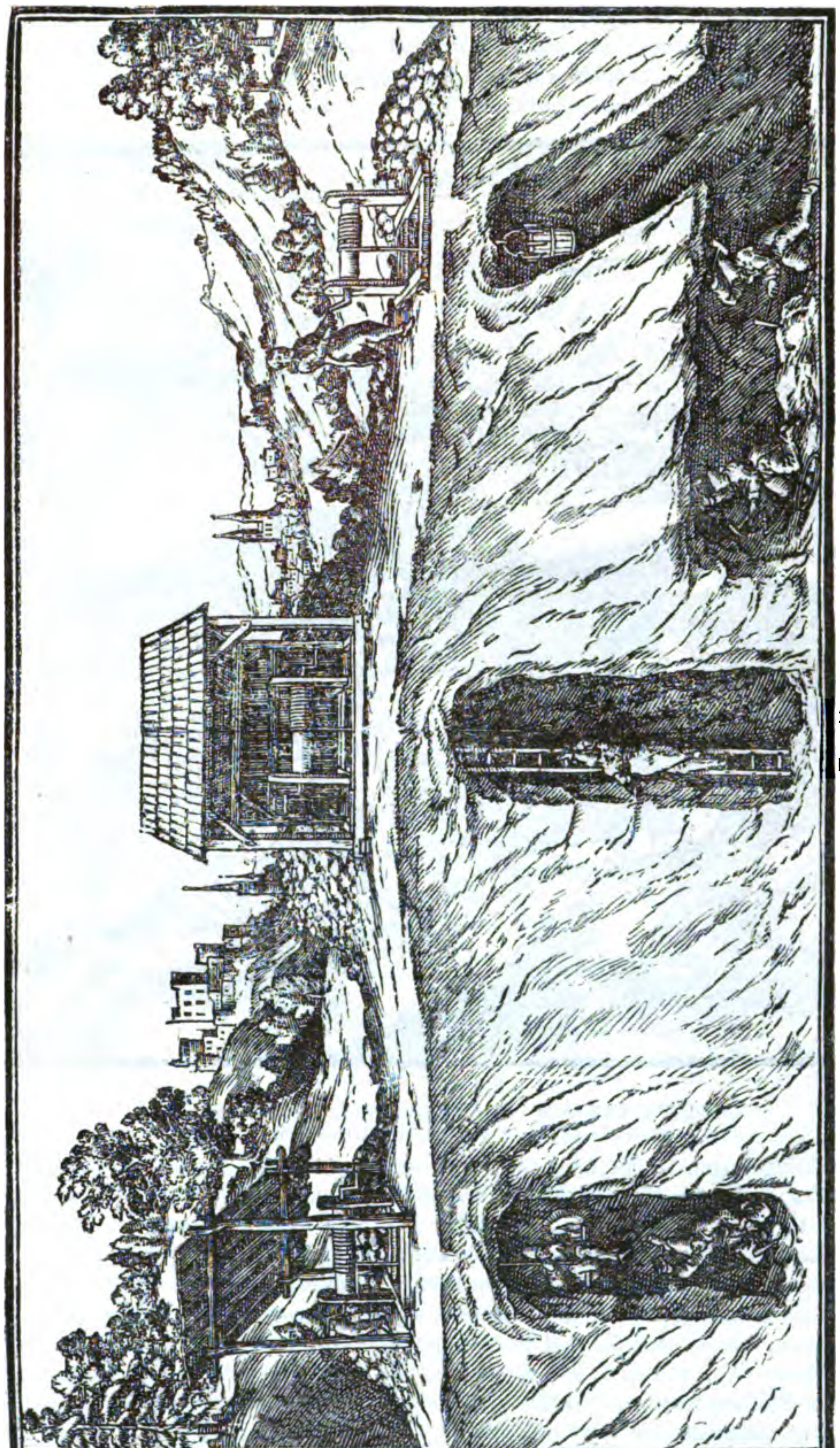


FIG. 10.

PICK AND GAD WORK.

(From Agricola's "Bergwerck Buch" (3d ed. of "de Re Metallica"), Basel, 1621.)

Torcy Tunnel, on the Centre Canal, in 1787. The construction of the Malpas Tunnel opened a new era in inland navigation, as it showed that canals could be carried through localities before considered impassable. Canal-building proper, however, it is said, was first revived, in modern times, in Italy, and in the low countries (Netherlands).

FIG. 11.
BRUSHING THE BAD AIR OUT BY SHAKING A CLOTH.
(From Agricola's "de Re Metallica," 1st ed., Basel, 1556.)

Canal-building began in England by the construction of the Duke of Bridgewater's Canal, $10\frac{1}{2}$ miles long, from Worsley Mill to Manchester; built by James Brindley, engineer, and designed to afford a direct transport outlet from the duke's coal-mines. The act of Parliament authorizing the construction of this work was passed in 1759, amended in 1760, and the first boat-load of coal was taken over the Barton Viaduct on July 17th, 1761. At Worsley, where a large basin was excavated of sufficient capacity to contain a great many boats, the canal did not stop, but entered the hill by a tunnel, the coal being directly shipped on the boats in the mines. This tunnel in Brindley's time was constructed about one mile in length, reaching to the different workings. It has since been enlarged with the mines, and is said in the aggregate to comprise over forty miles in all of subterranean navigation. These many canal-passages, however, can scarcely be called *tunnels* in the general sense of the word.

The earliest tunnel proper on an English canal, and the second modern tunnel in point of date, was the Harecastle Tunnel No. 1, situated on the Grand Trunk Canal (Trent and Mersey), projected by Mr. John Grundy, in 1761; the tunnel itself being built by Mr. James Brindley. Work was begun in 1766, and the heavier portion was completed in nine years; though the tunnel was not finally ready for opening until 1777. It was 2880 yards in length, 9 feet wide, and 12 feet high, and it would only permit a 7-foot boat, with a moderate loading, to pass. The passing was accomplished by leggers, so-called, a class of men who, lying upon their backs upon the freight, pushed against the sides and top of the roof with their feet, and thus moved the boat onward.

With this canal, tunnel-building on a large scale was fairly started in England; the canal was built largely in the interest of the Duke of Bridgewater, being commenced immediately on the successful completion of his first canal from Worsley to Manchester. The whole length was about 139½ miles, including the junctions with the Birmingham Canal and the river Severn; its object being to connect the Mersey with the Trent, and both with the Severn. Starting from the duke's canal at Preston on the Hill, it passed to a summit at the Harecastle No. 1 Tunnel, thence descending to the Valley of the Trent, which it followed to a junction with the Trent at Wilden Ferry. On the whole length of the canal, there were originally five tunnels: the Harecastle No. 1, 2880 yards long, 9 feet wide by 12 feet high; Hermitage, 130 yards; Barnton, 560 yards; Saltersford, 350 yards; Preston on the Hill, 1241 yards—the four latter all 17′ 4″ high and 13′ 6″ wide; and subsequently a sixth, the Harecastle No. 2, 2926 yards long, built by Telford in 1824, and located parallel to and only 26 yards distant from No. 1. The similarity of name has caused some confusion, so in this work the author has taken the liberty of distinguishing them as No. 1 and No. 2. The second tunnel was built owing to the first being found too small to accommodate traffic, as, from the "legging" operation, it required some two hours to pass a boat through the old tunnel. The new tunnel was built 16 feet high and 14 feet wide, of which 4′ 9″ was occupied by the towing-path, leaving 9′ 3″ of clear water. The Rive de Gier Tunnel (1770), on the Givors Canal, the Torcy Tunnel (1787), on the Centre Canal (both in France), were mentioned above: then came the Blisworth Tunnel (1798) in England, located on the Grand Junction Canal, 2820 m. long. There were also a number of early tunnels built on the various mountain-passes over the Alps, constructed at periods from 1801 to 1830.

These early tunnels, however, were all through hard ground, and their method of construction was therefore much similar to drifting on a large scale. In 1798, however, the earliest proposition was made for that work, which first showed tunneling through soft ground (and in this case the very softest) was practicable. It was then that Dodd proposed the communication between Gravesend and Tilbury by a passage under the Thames. In 1802, Vazie projected a tunnel from Rotherhithe to Limehouse. The project of a tunnel at Rotherhithe was also agitated by Chapman in 1804, but it was not until 1807 that a company was formed and work started. In that year, a shaft was sunk by Trevethick, and arrangements made to start the driftway, which was stopped in 1808 on account of an inflow of water; but the project was revived by Sir M. I. Brunel in 1823, who started the work anew on the 1st of January, 1826. In 1827, it was again abandoned upon a second irruption of water. In 1835, the government made some advances of money, and the work was resumed in March, 1836, with a new shield; the water again broke in on June 11th, 1836, and stopped the work for six weeks, after which it was pushed steadily to its conclusion in 1842.

We must not here forget the Tronquoy Tunnel, on the St. Quentin Canal, in France, built through sandy ground in 1803; for though the Thames Tunnel was proposed in 1798, we have seen that work on the one finally completed was not actually begun until 1807, so that the Tronquoy Tunnel was in fact the earliest tunnel built through ground requiring

arching; but owing to its prominence, the Thames Tunnel probably exerted greater influence on the subsequent history of tunnel construction.

It is also of interest to note that it is said that at Tronquoy a steam-engine was already in use in 1803. Starting almost simultaneously with the Tronquoy Tunnel was built the Riqueval Tunnel, also in 1803, on the same canal, and later also in France the tunnels of Noirieu, on the St. Quentin Canal (1822), St. Aignan (1822), Pouilly, on the Bourgogne Canal (1824), and then the Harecastle Tunnel No. 2 (1824), on the Grand Trunk Canal (Trent and Mersey), England, cited above.

In 1856, there were in England over forty-five tunnels on the various canals, aggregating some 219,827 feet (67,000 metres) in length, and in France about twenty, of a total length of 28,500 metres; among them the Noirieu Tunnel alone was some 12,000 metres long; also, among the earlier tunnels of the century, may be cited one on the Carlsgraf Canal, in Sweden, and another on the Castile Canal (6000 metres long) in Spain.

From the very beginning of tunneling, Ržiha has traced the development of the several systems of tunnel construction now in vogue in Europe, which will be elaborated in the following work, under the heads of the English, Belgian, German, and Austrian systems. The English, adhering to the example set in the Thames Tunnel, take out the full cross-section at once; the Belgians follow the principles of the tunnel built in 1828 on the Charleroy Canal; the Germans the system originally developed in the tunnels of Tronquoy and Pouilly, and advocated by Wiebeking, in 1814, as following the centre-core system also in use in the construction of the broad Bavarian beer-cellars. This centre-core system has been fixed in its distinctive nomenclature as the German system, but De Bauve, in the treatise on tunneling in his "Manuel de l'Ingénieur," has claimed it as the "French system," and it would seem with good reason, as it is admitted to have been devised and first put in execution by French engineers on a French tunnel (that of Tronquoy). The Austrians finally developed a plan corresponding to and based on the timber system in vogue in the Freiberg mines, and first applied by Meixner, in the construction of the Oberau Tunnel in Saxony (1837), and by Keissler, at the Gumpoldskirch Tunnel, near Vienna-Neustadt, in Austria (1839).

The first tunnel built on a horse-railroad (according to Ržiha)* was the Terre-noire single-track, near St. Etienne, in France, on the Roanne-Andrézieux horse-line, begun in 1826: 4921½ feet (1500 m.) long, 9·8 feet (3 m.) wide at springing line, and 16·4 feet (5 m.) clear height. In the Bulletin No. 5 (1856) of the Corps des Ponts et Chaussées, p. 5, there is also mention of a "Terre-noire" Tunnel, 1499 m. long, which, with some fourteen others, was built on the road from St. Etienne to Lyons in 1828–'33; in this reference, the tunnels of *Neaux on the Andrézieux-Roanne Road* are also mentioned as preceding steam railway tunnels. The first tunnels on a railroad on which locomotives were used were the two constructed on the Liverpool and Manchester Railroad, which was commenced by George Stephenson in 1826, and opened to traffic in 1830, though it was in October, 1829, that the memorable trial between the "Rocket," "Novelty," and "Sans Pareil" locomotives took place on this road. The first locomotive was used in England on the Stockton and Darlington line, opened in 1825.

In this connection, it is hardly necessary for us to touch on the early days of the steam-engine.† It may be well, however, to recall the leading dates pertaining to its history. The steam-engine was of slow development. For a century and a half, it had been experimented upon: by the Marquis of Worcester, to elevate water at Vauxhall, in 1656; by Pepin (who appears to have been the inventor of the principle of the safety-valve), in 1680; by Newcomen and Cawley, who completed an engine in 1710; by Savary, a Cornish miner, who constructed one to pump water from a mine in 1718; and by James Watt, who, about

* "Eisenbahn-Unter- und Oberbau," p. 335. † See Prof. R. H. Thurston's "Growth of the Steam Engine" for the best elaboration of this subject.

1770, succeeded in bringing it to something like perfection. This new power had been utilized on land and water. It had been made to assist the miners, to drive machinery, and to propel boats. The records of the province of Catalonia, in Spain, prove that, in 1543, Blasco de Garay, an officer in the service of the Emperor Charles V., made an experiment at Barcelona with a vessel which he forced through the water by means of steam generated in a large kettle.* While his experiment was successful, the results were not practically applied, and the matter was soon forgotten. Other experiments followed during the next two hundred years in different parts of Europe. Finally, in 1775, John Fitch, a citizen of Bucks County, Pennsylvania, a watch and clock maker by trade, commenced experimenting on the subject. He appears to have had no knowledge of even the existence of such a thing as the steam-engine, and he made every thing he needed as his experiments progressed, and in 1787 he actually completed, in all its details, a steamboat, with which he navigated the Delaware River successfully. Instead of paddle-wheels, the steam-power was applied to a number of oars, which worked upon either side of the boat in the ordinary manner. David Rittenhouse, the astronomer, certified, in December, 1787, that he had frequently seen Mr. Fitch's boat, and had been on board when it was "worked against wind and tide with considerable velocity by the force of steam only." Fitch continued his experiments, and, in 1790, advertised to carry passengers regularly to and from Burlington, Bristol, Bordentown, and Trenton, on the Delaware. The boat at that time ran, on an average, seven and a half miles per hour. Fitch, however, was in advance of his times; money was wanting to carry his project to full development and fruition. Finally, disheartened and impoverished, he became a wanderer over the world, and at last committed suicide in Kentucky, where his remains rest in an unmarked and almost unknown grave. In 1807, Robert Fulton, to whom the credit of inventing the steamboat is generally attributed, perfected his steamboat, and tried it upon the Hudson. His first attempt was made upon the Seine in 1803.

To return to the history of the steam-engine proper. In 1804, Richard Trevethick, foreman of a tin mine in Cornwall, completed a locomotive, which was tried on the Merthyr-Tydvil Railroad, in Wales. This machine was imperfectly constructed, and did not last long, but it demonstrated the fact that locomotives could be made practicable. In 1813, George Stephenson commenced the construction of his first locomotive, which he completed in 1814. After this, he built others, improving each time, until his "Rocket" took the premium on the grand test in October, 1829, on the Liverpool and Manchester Railroad. Among those who advocated the railroad previously to Stephenson's final success was Dr. James Anderson, who, in 1800, in a work entitled "Recreations in Agriculture," suggested the construction of railroads by the side of turnpikes, and was so minute in his details as to how they should be made, that his description might almost pass for that of a modern railroad. Also, about 1820, Thomas Gray commenced advocating the introduction of a general railway system similar to that now in use, and persevered in its advocacy until he was pronounced insane. Long before the opening of the Stockton and Darlington Railway, iron railways with horse transportation had been in use at the English collieries.

As to the early history of coal transportation, we find that "waggons and waines" were used at the English collieries at an early date; for Grey, in his "Chorographia" (1649), says of the coal trade of Newcastle-upon-Tyne:

(P. 19.) "There come ſometimes into this river for coales, three hundred fayles of ſhips."

(Pp. 24 and 25.) "Many thouſand people are imployed in this trade of coales; many live by working of them in the pits: many live by conveying them in waggons and waines to the River Tine: many men are imployed in conveying the coales in keeles from the ſtathes

* Wm. P. Sipes's "History of the Pennsylvania Railroad," Philadelphia, 1875, p. 2.

aboard the ſhips: one coal merchant imployeth five hundred or a thouſand in his works of coales: yet, for all of his labor, care, and coſt, can ſcarce live of his trade: nay many of them hath conſumed and ſpent great eſtates and dyed beggars. I can remember one of many that rayſed his eſtate by coale trade; many I remember that hath waſted great eſtates."

(P. 26.) "Some South gentlemen have upon great hope of benefit come into this country to hazard their monies in coale pits—Maſter Beaumont, a gentleman of great ingenuity and rare parts, adventuring into our mines with his thirty thouſand pounds; who brought with him many rare engines not known then in theſe parts; as the art to boore with iron rodds, to try the deepneſſe and thickneſſe of the coale; rare engines to draw water out of the pits; waggons with one horſe to carry down coales from the pits to the ſtathes to the river, &c. Within few years he conſumed all his money, and rode home upon his light horſe."

"The coale trade began not paſt four-ſcore years ſince; coales in former times was only uſed by ſmiths, and for burning of lime; woods in the ſouth parts of London, and other cities and towns growing populous, made the trade for coale increaſe yearely, and many great ſhips of burthen built, ſo that there was more coales wanted in one yeare than was in ſeven yeares, forty yeares by paſt. This great trade hath made this towne to flouriſh in all trades."

In these extracts from Grey, however, there is no mention of tramways; these were plainly in use in the north of England in 1676, for Lord Keeper Guildford, who rode the northern circuit that year, thus describes them: * "The manner of the carriage is by laying rails of timber from the colliery down to the river exactly straight and parallel; and bulky cars are made with four rowlets fitting these rails, whereby the carriage is so easy that one horse will draw down four or five chaldron of coal, and is an immense benefit to the coal merchants."

Brand tells us of these wagons in his "History of Newcastle" (1789, vol. ii., p. 687), that "the first waggons are said to have wanted the conveniencies of letting out at the bottom, having been emptied with shovels like the present ballast waggons. It appears by the old books of the Hostmen's Company, A.D. 1600, that the then coal waines contained eight bowls of coal, and some scarce seven bowls. The present waggons contain more than twice that quantity." Also (p. 687) Brand says: "There is a tradition among the people belonging to the coal works that the first waggon that was used for this purpose in the vicinity of Newcastle was lined with tin, and filled with the liquor called punch. It is easy to conjecture that the unlading of such a waggon would prove a very grateful task to the thirsty workmen."

When the "waggon-ways" were first protected by iron sheeting, it is difficult to ascertain positively. In 1610, there was a patent granted to Simon Sturtevant (for thirty-one years) "for divers mechanic arts and myſteries of his own invention, whereby all kinds of workes and materials, as iron, ſteele, lead, ... and ſuch like, ... may bee well made and wroughte with ſea coale, pit coale, earth coale, and bruſh fuel, whereof the woodes now generally waſted . . . . . may be preſerved." † Also, a patent for founding iron with coal was granted to Simon Startwort in 1622; ‡ he, however, did not succeed with the business, and we subsequently find § "that there occurs among the projected monopolies of the year 1627 a charter to three persons for the sole practice of their new invention for the melting of iron ore, and making the same into cast works and bars, with sea coal and pit coal only." ‖

* "History of Newcastle," Brand, 1789, vol. ii., p. 687.

† Weale's "Quar. Papers on Engineering," vol. v.

‡ "The Coal Regions of Pennsylvania," by E. C. Bowen, 1848.

§ Brand's "History of Newcastle," London, 1789, vol. ii., p. 280.

‖ However, iron-founding in England dates back to the fifteenth century. Charles Wilkins, in his "History of Merthyr-Tydvil," cites an iron plate standing under the hammer-block on the site of an old furnace near Troedyrhiw, which was found to bear the date 1478; also he says further: "One hundred years after this date, a record exists of iron works erected opposite Duffryn Furnace;" and "in the days of Elizabeth (i. e., about 1570) iron furnaces were at work about Merthyr, but they all used wood." (British Parliamentary Report on Coal, vol. i., 1871, App. 21.)

In 1750, there are said * to have been 300 furnaces in England, yielding about 75,000 tons of metal annually, and that, after the successful application of coal to iron-making, the number was nearly quadrupled in one year, and from 1796 the iron trade of England may be said to have effectively commenced. According to George Stephenson, the first rails wholly made of iron were cast in 1766.† The Surrey Iron Railway Company (1801) was the first incorporated by act of Parliament for purposes of transportation, but before the locomotive was introduced on the Stockton and Darlington line, these railways were chiefly for coal traffic.

Tunnels, of course, multiplied rapidly in England with the extension of railways, and during the twelve or fifteen years following the construction of the Liverpool and Manchester line, there were a large number of tunnels built throughout the kingdom, among them being the famous Kilsby, Box, and Woodhead tunnels. The first tunnels on a steam-railway in France were those built on the St. Germain line in 1837. Subsequently, the ones on the Versailles, the Gard, and the Rouen lines raised the total length of tunnels in France in 1845 to 12,833 m. (42,105 feet.) The report of the Corps des Ponts et Chaussées ‡ on tunnels for 1856, shows at that date a total on French railroads of 126 tunnels, of a total length of 65,106 metres. It also appears that there were then 62 additional ones proposed, of a total length of 41,000 metres, 22,783 metres being actually under construction. Among the noted early French tunnels may be cited the Nerthe, Arschwiller, Rilly, La Motte, Lormont, and Alouette. In Belgium, the Cumptich Tunnel, built in 1835, on the "Chemin de l'Etat," seems to have been the earliest. In Germany (Prussia and other states), the earlier lines were so located as to not require much tunnel-work; and we have seen that the Oberau Tunnel (1839), on the Leipsic-Dresden line, in Saxony, was the first. In Austria, we have seen that Ržiha gives the Gumpoldskirch Tunnel as the first. A tunnel at Eriebitz (perhaps the same), on the "North" line, is mentioned in the Ponts et Chaussées Report (above cited) as an early Austrian one. In 1856, there were some 50 tunnels in Austria, of a total length of 13,522 metres. In Italy, the Naples-Castelamare line, opened in 1840, had several tunnels. In 1856, the total Italian tunnels amounted to 10,181 m.; the Bologna-Pistoja line is especially remarkable for its semi-subterranean character. Among the early Swiss tunnels especially to be noted is the Hauenstein, commenced in 1853 and finished in 1858.

The history of tunneling after the construction of the earlier lines is, of course, identical with that of the various railway systems, until tunneling, in the inception of the Mont Cenis Tunnel in Europe and the Hoosac Tunnel in America, entered its last and greatest phase, that introduced by the adoption of machine rock-drills and high explosives. And now it is time that we should turn and trace the history of tunneling on the west of the Atlantic; and to do so, it will be necessary first to take a short retrospect of the early history of canal and railroad engineering in America, and note, in concise form, the dates at which the several States began their systems of internal improvements.

It appears that the first large canal located in the United States was the Schuylkill and Susquehanna (Union Canal), in Pennsylvania, on which work was actually commenced in 1791. In the very early work in Pennsylvania should also be included a canal around the Conewago Falls of the Susquehanna, 1¼ miles long, built by a company chartered in 1793, and executed soon after. Among the early pieces of canal-work in the country should be also noted some commenced and partially finished on the Dismal Swamp Canal, in North Carolina, between 1786 and 1791; also some work was done about the same time on the Potomac, James, and Rappahannock Rivers. The Hadley Canal, 2 miles long, and the Montague

* "The Coal Regions of Pennsylvania," by E. C. Bowen, 1848.

† See "The Pennsylvania Railroad," by Wm. B. Sipes, Philadelphia, 1875, p. 2, "Early English Railroads."

‡ Bulletin No. 5, 1856, "Statistiques des Ouvrages d'Art."

TABLE 1.*

Early Canals and Railroads of the United States and Canada.

CANALS.

STATE.	NAME.	LOCATION.	LENGTH IN MILES.	DATE.	ORIGINAL COST.
Alabama.........	Muscle Shoals.	Along the Tennessee River.	....	35¾ miles completed before 1840.	$571,835
Connecticut......	Farmington.	New Haven to Suffield.	56	Commenced 1825; completed prior to 1830.	600,000
Delaware........	Chesapeake and Delaware.	Delaware River to Chesapeake Bay.	13½	Work begun 1804 and subsequently suspended; relocated 1822; completed 1829.	2,750,000
Florida..........	Lake Winico and St. Joseph's Canal and Railroad.	....	12	Incorporated 1835; completed 1836.	....
Georgia..........	Savannah, Ogeechee and Alatamaha.	....	16	Commenced 1825; completed 1829.	165,000
Louisiana........	Carondelet.	New Orleans to Bayou St. Johns.	2	Charter granted 1805. Built soon after.	....
"	Orleans Bank.	New Orleans to Lake Pontchartrain.	4¼	....	1,000,000
Maine	Cumberland and Oxford.	From tidewater near Portland to end of Long Pond.	20¾ (also 30 of river navigation)	Completed 1829.	250,000
Massachusetts....	South Hadley.	For passing rapids on Connecticut River at South Hadley.	2	Built by a company; chartered in 1792.	....
"	Montague.	For passing Montague Falls on the Connecticut River.	3	Built by a company; chartered in 1792.	....
"	Middlesex.	Connecting Boston Harbor, at Charlestown, with Merrimac (now Lowell) on the Merrimac River.	27	Incorporated in 1789; commenced 1793; opened 1804; completed 1808.	....
Maryland.......	Chesapeake and Ohio.	Georgetown, D. C., to Pittsburg, Pa., along s. w. border of Maryland; stops at Cumberland.	341½	Commenced 1828; opened 1850.	180 miles opened in 1850 at a cost of about $12,000,000.
New Hampshire..	Bow.	At Gardner's Falls, four miles below Concord.	¾	Completed 1812.	25,000
New Jersey	Delaware and Raritan.	Bordentown to Trenton, and thence to New Brunswick.	42	Incorporated in 1824; commenced 1831; completed 1834.	2,500,000
" "	Morris.	Phillipsburg to Newark and Jersey City.	....	Commenced 1825.	....
New York........	Mohawk and Little Falls.	At the Little Falls of Mohawk River.	1	1798.	....
" "	Rome.	Connecting Mohawk River and Wood Creek at Rome.	2	1798.	....
" "	Champlain.	Erie Canal to Whitehall, N. Y.	11 (76 also of river navigation)	Commenced 1816; completed 1819.	1,179,872
" "	Erie.	Albany to Buffalo.	363	Commenced July 4, 1817. Portion from Utica to Montezuma opened 1819; whole canal opened 1825.	Original cost before enlargement in 1835, $10,731,595.
" "	Delaware and Hudson.	From Hudson River (near Kingston, N. Y.) to Honesdale, Pa.	108	Commenced 1825; completed 1829.	2,500,000
North Carolina...	Dismal Swamp.	Cut through the great swamp at the n. e. corner of North Carolina and s. e. corner of Virginia.	....	Commenced at a very early date; opened 1822, and subsequently extended.	....
Ohio............	Ohio and Erie.	Portsmouth to Cleveland.	307	Commenced 1825; completed 1832.	5,000,000
Pennsylvania.....	Schuylkill and Susquehanna, subsequently "Union Canal."	From Schuylkill River, near Reading, to Middleton, on the Susquehanna.	82	First located 1762; commenced 1791; four miles opened 1794; work suspended 1795 until 1821; completed 1827.	....
"	Delaware and Schuylkill.	Philadelphia to Norristown.	....	Incorporated 1792, and soon after commenced but never completed.	....
"	Schuylkill Navigation.	Philadelphia to Port Carbon.	58 (also 50 miles of river navigation). Total 108	Commenced 1815; partly done 1821; completed 1826.	2,500,000
"	Lehigh Navigation.	Easton to Whitehaven.	46 (part river navigation)	Commenced 1827; opened from Mauch Chunk to Easton, 46 miles, in 1829.	....
"	Pennsylvania Canal.†	Susquehanna Division (Central).	244	Commenced 1826 (ground broken July 4th).	....
Rhode Island....	Blackstone.	Providence, R. I., to Worcester, Mass.	45	Commenced 1826; completed 1828.	600,000
South Carolina...	Santee.	Connects Charleston Harbor with Santee River.	22	Completed 1802.	700,000
Virginia..........	James River and Kanawha Canal and Railroad Co.	Projected to connect Richmond with the Ohio River at the mouth of the Great Kanawha.	485 (also 20 miles North River improvement)	Portion from Richmond to Lynchburg commenced 1836; opened from Richmond to Lynchburg 1840.	Richm'nd to Lynchburg, $6,986,668; Lynchb'g to Buchanan $2,422,556; above do., unfinished, $1,047,645. Total, $10,436,869.

* For data concerning these early records of public works in the United States, the author is indebted, among other sources, to "Notes on the Internal Improvement of Pennsylvania," by George W. Smith, in the "Register of Pennsylvania" for 1828; "Internal Improvements of the United States," by "A Citizen of the United States," Philadelphia, 1830; Tanner's "Canals and Railroads of the United States" (1840).

The records drawn from these and other sources have further had the benefit of especial revisions, corrections, and additions made by Messrs. Benj. H. Latrobe, Baltimore, Md.; John B. Jervis, M. Am. Soc. C. E., Rome, N. Y.; W. Milnor Roberts, M. Am. Soc. C. E., New York City; Solomon W. Roberts, Ch. Eng'r, North Pennsylvania Railroad, Phila.; William H. Wilson, Cons. Eng'r, Pennsylvania Railroad, Philadelphia.

† The Delaware, Central, and Western Divisions of the Pennsylvania Canal were all in progress in 1828.

RAILROADS.

STATE.	NAME.	LOCATION.	LENGTH IN MILES.	DATE.	ORIGINAL COST.
Alabama.......	Alabama, Florida, and Georgia.	Pensacola, Fla., to Montgomery, Ala.	156¼	Built before 1840.	$2,500,000
Connecticut....	Housatonic (one tunnel).	Sheffield, Mass., to Bridgeport, Ct.	73	Commenced 1837.	1,000,000
Delaware	New Castle and Frencht'wn.	From New Castle to Frenchtown.	16	Commenced 1830; completed 1832.	400,000
Georgia.........	Georgia.	Augusta to Atlanta.	171	Built before 1840.	3,800,000
Louisiana......	Pontchartrain.	New Orleans to Lake Pontchartrain.	4½	Built in 1830-'31.	....
Maine...	Bangor and Orono.	Bangor to Orono.	10	Incorporated 1835; completed 1836.	....
Massachusetts..	Quincy.	From Quincy granite quarries to tidewater (5 feet gauge).	3	Located 1825; completed 1826.	50,000
"	Boston and Lowell.	Boston to Lowell.	26½	Commenced 1831; opened 1835.	... .
"	Boston and Providence.	Boston to Providence.	41	Incorporated 1831; opened 1835.	1,782,000
Maryland	Baltimore and Ohio.	Projected to connect Baltimore with Ohio River. First built from Baltimore to Harper's Ferry.	81 Baltim're to Harper's Ferry; 298 Harper's Ferry to Wheeling.	Incorporated in 1827; commenced 1828; first division opened 1830; op'd throughout to Wheeling, W. Va., 1853.	Cost to Nov., 1853, $20,708,028
New Hampshire	Nashua and Lowell.	Nashua, N. H., to Lowell, Mass.	15	Completed 1838.	Up to Jan., 1839, $285,052
New Jersey....	Camden and Amboy.	Camden to South Amboy.	61	Commenced 1830; completed 1837.	1,238,000
New York......	Saratoga and Schenectady.	Saratoga to Schenectady.	21½	Commenced 1831; opened July 12, 1832.	297,237
" "	Albany and Schenectady.	Albany to Schenectady.	17	Excursion train ran 1831; completed 1832.	....
" "	Harlem (one tunnel).	City Hall, N. Y. City, to Harlem.	8	Built 1836-'37.	1,100,000
" "	Utica and Schenectady.	Utica to Schenectady.	80	Completed 1836.	....
" "	Albany and Worcester.	Albany to Worcester.	156	Completed 1837.	....
North Carolina.	Wilmington and Raleigh.*	Wilmington to Weldon.	161	Commenced 1836; completed 1840.	....
Ohio..........	Mad River and Sandusky City.	From Tiffin to Sandusky City.	30	1833 or 1834.	....
Pennsylvania...	Crum Creek.	From Thomas Leiper's stone quarries, Crum Creek, to landing on Ridley Creek, Delaware Co., Pa.	1	1808; continued in use nineteen years.	....
" ..	Mauch Chunk.	Mauch Chunk to coal mines.	9	Constructed 1827.	31,500
" ..	Terminal R. R. of Delaware and Hudson Canal Co.	Honesdale to coal mines at Carbondale.	16	Constructed 1828.	....
" ..	Columbia and Philadelphia.	Columbia to Philadelphia.	81½	Commenced 1828; 20 miles completed 1832; whole line, 1834.	3,734,577 Built by State.
" ..	Allegheny Portage (one tunnel four miles from Johnstown).	Hollidaysburg to Johnstown.	36½	Commenced 1831; completed 1834.	1,634,357
Rhode Island ..	Providence and Stonington.	Providence to Stonington.	47	Completed 1837.	2,000,000
South Carolina.	South Carolina.	Charleston to Hamburg.	135¾	Commenced 1830; completed 1834.	1,750,000
Virginia.	Richmond, Fredericksburg, and Potomac.	Potomac River, at mouth of Aquia Creek, through Fredericksburg to Richmond.	61 to Fredericksburg; 75 whole length.	Completed from Richmond to Fredericksburg prior to 1840.	....

CANADA.

CANALS.

NAME.	LOCATION.	LENGTH IN MILES.	DATE.	ORIGINAL COST.
Lachine.	Montreal to Lachine.	8½	Opened 1825.	$438,404
Welland.	Lake Ontario to Lake Erie.	27	Commenced 1825; completed 1829.	....
Rideau.	Ottawa to Kingston.	127	Commenced 1826; completed 1832	....

RAILROADS.

NAME.	LOCATION.	DATE.
La Prairie and St. Johns.	To unite Lake Champlain with the St. Lawrence.	Built prior to 1840.

* Original charter, dated 1833, was for railroad from "Wilmington to Raleigh." Amended in 1835 to "Wilmington to some point on Roanoke." Hence named "Wilmington and Raleigh Railroad," although the line did not pass within fifty miles of Raleigh when constructed.

Canal, 3 miles long, both in Massachusetts, were built by companies chartered as early as 1792; the Santee Canal (22 miles), in South Carolina, was built in 1802; and the Carondelet Canal (2 miles) in Louisiana, was chartered in 1805. The Middlesex Canal (27 miles), in Massachusetts, comes next in 1808, then the Champlain Canal, in New York, commenced in 1816 and completed in 1819; and, finally, the Erie Canal (363 miles), in New York, was commenced in 1817 and completed in 1825; the Champlain Canal, above noted, was built in connection with it.

The building of the Erie Canal, a colossal work at any time, and especially so in the early days of the country, gave an impetus to the spirit of public improvement in all parts of the Union. Though New York was the first State, therefore, that had the pluck to put into execution schemes for public improvement on a large scale, there can be no question, on the other hand, that Pennsylvania can fairly lay claim to being the pioneer State in the matter of the early inception of such work. William Penn, in his "Proposals for a Second Settlement in the Province of Pennsylvania," published in 1690, alludes to the practicability of effecting a "communication by water" between the Susquehanna and the Schuylkill.

The matter was revived and agitated in Pennsylvania, between 1750 and 1760, by some energetic citizens, and, in 1762, David Rittenhouse and Dr. William Smith surveyed and leveled a route for a canal to connect the waters of the Susquehanna and Schuylkill Rivers by means of the Swatara and Tulpehocken Creeks. The Union Canal, subsequently built, was located on a portion of this route, the first one surveyed for a canal in the colonies. David Rittenhouse subsequently held the position of astronomer, and Dr. Smith that of provost, of the University of Pennsylvania.

Duly to appreciate the enterprise of the age and the people, we must remember that the projectors of this route contemplated nothing less than the ultimate junction of the waters of the Delaware with the Ohio and Lake Erie, on a route of some 582 miles, with an elevation of some 3000 feet at the Allegheny Mountains to overcome; that the scheme was all substantially carried out in time; that this was a day in which the words "engineering" and "capital" were comparatively unknown in the colonial vocabulary; that no canal was then in existence even in the mother country, and the Duke of Bridgewater's navigation was but just begun.

In 1764, the first survey for a canal to connect Chesapeake Bay with the Delaware River was made, and in 1769 a second survey was conducted under the direction of the American Philosophical Society; in this year, the provincial legislature authorized a full survey of the Pittsburg and Erie route proposed by Rittenhouse and Smith, and there is little question but that had the stirring events of the Revolution not interfered, these projects would at once have been put in execution. On September 29th, 1791, the legislature incorporated a joint-stock company to connect the Susquehanna and Schuylkill Rivers by canal and slack-water navigation, and in a subsequent act of April 10th, 1792, the intention of connecting the eastern with the western and northern parts of the State is distinctly expressed in the act of incorporation of the Delaware and Schuylkill Canal, which was intended to carry out a link in the scheme. Work was begun on these canals, but, owing to financial embarrassments, it was discontinued in 1795. In 1811, these two early charters were united in the "Union Canal Company;" the Delaware and Schuylkill Canal, however, was never completed. In 1819, the legislature (of Pennsylvania) guaranteed an interest of six per cent on the stock of the Union Canal Company, and, in 1821, operations were resumed, and the canal finally completed in 1827, under the direction of Canvas White as chief-engineer, Simeon Guilford, principal assistant, thirty-five years having thus elapsed from the commencement of the work in 1792, and sixty-five years since the date of the first survey. Meantime, owing to the delay in the completion of this work, the Schuylkill Navigation had been completed before it. This

work had been commenced in 1815 (the company being incorporated on May 8th), and the lower part of the canal, from Norristown to tide-water at the Falls of the Schuylkill, was completed and brought into use by 1821, the whole being completed in 1825. It was an important piece of work, being the outlet for the Schuylkill coal regions, and this canal is of especial interest to us, as upon it the FIRST TUNNEL EVER CONSTRUCTED IN THE UNITED STATES was located. This was the tunnel above Auburn, at the Orwigsburg Landing, commenced in 1818 and opened for use in 1821.* It was cut through red shale 20 feet wide by 18 feet high (from canal-bottom), and was originally 450 feet long; arched for about 75 feet in from each portal. The highest point of the hill over this tunnel was only some 40 feet, and had it been located but a short distance down the ridge where the railway-cut now is, the tunnel might easily have been altogether avoided. This location also would have given a better alignment for the canal itself, for, in fact, in order to get a tunnel, they had to almost turn a right angle to the previous course of the canal, so as to get sufficient height to tunnel under. It is said that the tunnel, from the novelty of such a structure, excited great attention, many people coming in stages and private conveyances from Philadelphia to view it, and that it, in fact, was one of the chief causes in promoting and exciting general public interest in the canal itself. In 1834–'37, the tunnel was shortened to about half its original length; in 1845–'46, it was enlarged in width to 22 feet, and further shortened to a length of only 160 feet, and, finally, in 1855–'56, it was wholly taken out in open cut (the dotted lines in the sections show the slopes), so that our first American tunnel is now "an airy nothing." Even the name of the engineer who located and built it is not known, and the sketch and section in Fig. 12 must stand as the sole record of this first precursor of the art in America, which has given us, in the growth of fifty years, the long line of tunnels to whose history we can look back to-day.

The Champlain and the Erie Canals, in New York, were also completed before the Union Canal, and others were already under way—among the early New York ones being the Black River Navigation (about 40 miles), the Chenango (about 97 miles), and others. In Pennsylvania, there was the Lehigh Navigation, followed by the Delaware Division of the Pennsylvania State Canals, and subsequently by the Central and Western Divisions. Further work was either going on or had been completed in the other States; among them the Farmington (Ct.); Chesapeake and Delaware (Del.); Savannah and Ogeechee (Ga.); Lake Pontchartrain (La.); Cumberland and Oxford (Me.); Middlesex (Mass.); Chesapeake and Ohio (Md.); Dismal Swamp (N. C.); Bow (N. H.); Ohio and Erie (Ohio); Blackstone (R. I.); James River (Va.); and many others, these being but cited as types.

As showing the work done in Pennsylvania in the early days from 1791 to 1828, it has been estimated † that between those years some $22,000,000 were expended by the State and by private corporations on the various canals, rivers, turnpikes, railways, and bridges of the State, exclusive of the sums expended by the counties on roads, bridges, etc., and exclusive of the sums expended by the State prior to 1791; further that the additional improvements actually under construction in 1828, and to be completed within three years, were estimated to cost some $12,500,000 additional.

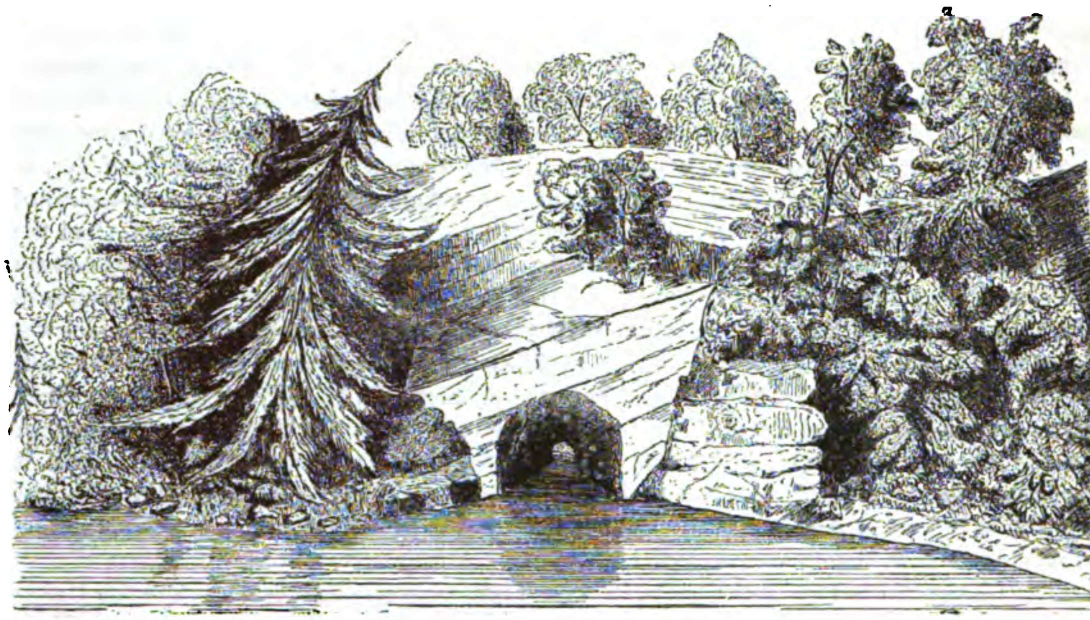
Between 1791 and 1828, 265 companies were incorporated by the legislature for purposes of internal improvement, and of these 36 were railroad, canal, or navigation companies, and 14 had commenced operations in 1828: it must also be remembered that the State

* For the illustrations of this tunnel, the author is indebted to Mr. W. Lorenz, Chief-Engineer Philadelphia and Reading Railroad Company; the dates and general data were kindly furnished, through Mr. Lorenz, by Mr. J. F. Smith, Cons. Eng'r Canals, P. & R. R.R. Co.

† "Notes on the Internal Improvement of Pennsylvania," by Geo. W. Smith, in the "Register of Pennsylvania," 1828, p. 406.

canals had also then been commenced. In 1828, there had been completed in Pennsylvania of

Canals	301½	miles.
Slack-water Navigation	117¼	"
Railways	17¾	"
Total	436½	"



Front View sketched by Mr. Charles Knoderer, Principal Assistant Engineer of Construction in 1855–'56.

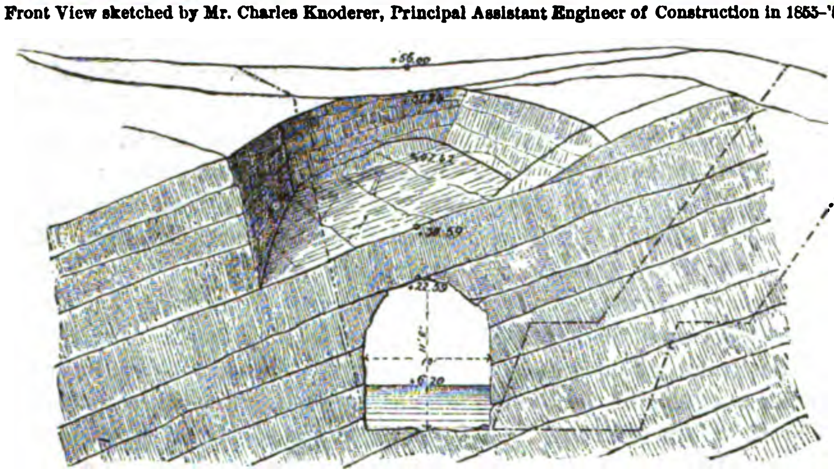


FIG. 12.

View and Section of the First Tunnel ever built in the United States, located on the Schuylkill Navigation above Auburn. Built 1818–'21. Taken out in open cut as shown by dotted lines in 1855–'56.

at a total cost of some $11,019,000. There were further in course of construction, and to be finished within three years, of

Canals	746½	miles
Slack-water Navigation	10	"
Railways	149¼	"
Total	905¾	"

Of this 149½ miles of railway, part was to be at State cost—viz., the Allegheny Portage, 41 miles, located from Johnstown to Frankstown, and the Columbia and Philadelphia Railway, 84½ miles. These lengths were in part 36⅝ miles and 81½ miles as the lines were finally completed. The total length of canals already built or in course of construction, with their terminal or connecting railroads, up to July, 1829, is given as 4417 miles in the "Internal Navigation of the United States," by "A Citizen of the United States" (Philadelphia, 1830).

We thus have seen that Pennsylvania inaugurated canal-building in the Union. It is further well established that Pennsylvania also took the lead of the other States by many years in railroad construction.* In 1806, the first experimental railroad-track built in the United States was laid out by John Thomson, Civil Engineer, of Delaware Co., Pa., and constructed, under his direction, by Somerville, a Scotch millwright, for Thomas Leiper, of Philadelphia. It was 60 yards in length, and graded an inch and a half to the yard. The gauge was 4 feet, the sleepers 8 feet apart. The experiment with a loaded car was so successful that Leiper, during 1806, had the first practical railroad built in the United States constructed for the transportation of stone from his quarries on Crum Creek to his landing on Ridley Creek, Delaware County, Pa., a distance of about 1 mile. It continued in use until superseded by a canal in 1828. The line of the road can still be seen.

The second railway in the States was the "Quincy," in Massachusetts, 4 miles long, constructed in the autumn of 1826. It will be interesting to note that the line was originally built to carry granite for the Bunker Hill Monument. The Mauch Chunk Railway, in Pennsylvania, 9 miles long, was next built in the spring of 1827 by the Lehigh Coal and Navigation Company.† This company was the first to regularly send anthracite coal to market in the United States, and its history was briefly as follows:‡ In 1793, the "Lehigh Coal Mine Company" was formed, and they at once "took up," under warrants from the Commonwealth, about 10,000 acres of coal land. The company then proceeded to open the mines, and made an appropriation of ten pounds ($26.67) to construct a road from the mines to the Lehigh River landings.

This first attempt proved abortive, and it was not until 1813, after the company had made a lease of their lands for ten years to Miner, Cist & Robinson, that two out of five arks of coal shipped on the Lehigh by this firm reached Philadelphia; the other three were wrecked in transit. It is also said that an ark was previously shipped by William Turnbull, in 1807, from Lousane, by which two or three hundred bushels reached Philadelphia, but, upon trial, it was rejected as worthless. The property subsequently came into the hands of the firm of White, Hauto & Hazard, and by them the "Lehigh Navigation Company" was formed in 1818.§ In the same year, the "Lehigh Coal Company" was also formed by the same parties, for the purpose of making a road from the river to the mines, and of bringing coal to market by the new navigation. This road was laid out in the autumn of 1818, and finished in 1819. It is said to have been the first road in the country ever laid out by an instrument on the principle of dividing the whole descent into the whole distance, as regularly as the ground

* "History of Delaware County, Pa.," by George Smith, M.D., Philadelphia, 1862, p. 389, and "History of the Pennsylvania Railroad," Wm. B. Sipes, Philadelphia, 1875, p. 4.

† Some time in the same year (1827), Abraham Potts, in the Schuylkill region, built a line half a mile long, from his coal mine to Port Carbon. (See E. C. Bowen's "Coal Regions of Pennsylvania," 1848, p. 27.)

In 1826 there was *incorporated* in the Schuylkill region a company to build a railroad from Pottsville to Danville, 41 miles; by a supplementary act, the company was authorized to extend branches to Sunbury and Catawissa. Another company was incorporated in 1828 to build a railway from Mine Hill to Pottsville, but nothing was immediately done on either project. (See Geo. W. Smith's "Notes on the Internal Improvement of Pennsylvania," in the "Register of Pennsylvania," 1828, p. 418.)

‡ "History of the Lehigh Coal and Navigation Company," Philadelphia, 1840.

§ Abijah Smith, of Plymouth, Pa., first applied blasting to anthracite coal mining in America, in 1818. (See "Engineering and Mining Journal," New York, May 30th, 1874.)

would permit, with no undulation. It was intended to be used as a railroad as soon as the business would warrant the expense of placing rails upon it. In 1820, the "Lehigh Navigation Company" and the "Lehigh Coal Company" consolidated as the "Lehigh Navigation and Coal Company," and 365 tons of coal were sent to Philadelphia as the first-fruits of the joint concern, and sold at $8.50 per ton. This quantity of coal completely stocked the market for the year, and was with difficulty disposed of. It should here be noted that no anthracite coal came to market from any other source than the Lehigh prior to 1825 as a regular business.

The shipments from the Lehigh and the Schuylkill regions from 1820 to 1825 were:

DATE.	LEHIGH.	SCHUYLKILL.
1820	365	
1821	1,073	
1822	2,240	1,480
1823	5,823	1,128
1824	9,541	1,567
1825	28,393	6,500

In 1821, there was again a rearrangement of the company, and its name was finally changed to "The Lehigh Coal and Navigation Company." In 1826, the coal production had increased to 31,200 tons shipped in that year, and it was becoming difficult to keep the turnpike to the mines in good order, so that it was determined to convert it into a railroad, which was completed in May, 1827. This extended notice has been given of the history of the Lehigh Coal and Navigation Company, as by it not only was this one of our two earliest railroads built, but to it we owe the FIRST LARGE MINING TUNNEL, and the SECOND TUNNEL in point of date, constructed in the United States. This was the "Hacklebernie" Tunnel near Mauch Chunk, Pennsylvania, commenced in 1824, work suspended in 1827, resumed in 1846, final length 2200 feet. It was driven about 16 feet wide by 8 high, and at a distance of several hundred feet from the entrance a ventilating hole several inches in diameter was bored down to it vertically from the surface of the hole. The tunnel was driven in to reach a coal-vein, and before its stoppage, in 1827, had advanced through hard conglomerate some 790 feet. Thirty-seven hundred and forty-five cubic yards of rock were removed, at a cost of $26,812, or $7.16 per cubic yard. It is said* that at this date so little was known of tunnels in the United States, that when James Clarke (afterward Canal Commissioner) proposed a continuous canal between Philadelphia and Pittsburg with a tunnel four miles long, through the Allegheny Mountains, his "tunnel" idea was almost universally ridiculed as that of a visionary schemer. And the above Mauch Chunk Tunnel when first projected by Josiah White was very generally known by the name of "White's Folly" among those skeptical of its success. Nevertheless, there were others who held larger views, for we find that the grand project of tunnelling the Hoosac Mountain, so recently completed, was mooted half a century ago. As far back as 1825, a Board of Commissioners, with Laommi Baldwin as engineer, were appointed in Massachusetts to ascertain the practicability of making a canal from Boston to the Hudson River, in the vicinity of the junction of the Erie Canal with that river. At the Hoosac Mountain, their examinations were extended both to the north and south of the present line of tunnel, with a view to discover some other route by which it might be avoided; but increased distance and lockage, and difficulty of procuring water, induced them to give preference to the tunnel.

* For much specific information concerning these early tunnels, the author is directly indebted to Mr. W. Milnor Roberts, M. Am. Soc. C. E. Mr. Roberts, then a young engineer, was either directly engaged on many of the tunnels or on the works with which they were connected, so that the data here given are on the best of authority. Among these tunnels were, the Summit Level, Mauch Chunk (Hacklebernie), Allegheny Portage (the data concerning this tunnel, however are chiefly derived from Mr. Solomon W. Roberts), Elizabethtown, and Conemaugh and Grant's Hill tunnels.

In their report of 1826, they say: "There is no hesitation therefore in deciding in favor of a tunnel, but even if its expense should exceed the other mode of passing the mountain, a tunnel is preferable, for the reasons which have been assigned. And this formidable barrier once overcome, the remainder of the route, from the Connecticut to the Hudson, presents no unusual difficulties in the construction of a canal."

To show that a spirit of opposition to tunnel construction was not confined in these early days to America, it may be well to note the following testimony, taken in 1836, in England, before a Parliamentary Commission relative to the Britton Railway Bill.* Sir Anthony Carlisle, M.D., Vice-President of the College of Surgeons, testified as to the general injury to the health of passengers from passing through tunnels; liability to catch cold, inflammation of the lungs, erysipelas, rheumatism, and lumbago. On cross-examination: "I know from experience, it is difficult to discharge a tunnel or a large room of any stagnant or quiescent mass of air; and I believe a 600-yards tunnel of the dimensions given would neither discharge itself nor could it be discharged by any ordinary known means."

Before the same commission, Dr. James Johnson testified that, "the reverberation of sound is of more consequence than the vicissitudes of temperature. . . . . The noise in going 30 miles an hour would give a very great shock to delicate people."

With regard to the effect upon the nerves resulting from passing under arches thirty, forty, and fifty yards long, Dr. Johnson quoted the following from a pamphlet he had published some two years previously, as describing his own feelings on his first experience:

"The deafening peal of thunder, the sudden immersion in gloom, and the clash of reverberated sounds in a confined space, combined to produce a momentary shudder, or idea of destruction, a thrill of annihilation."

To return to our history of tunneling in America. The "Summit Level," or Lebanon Tunnel,† on the Union Canal, begun in 1824 and finished in 1826, was the second canal tunnel, and the third tunnel built in the United States: Canvas White, chief-engineer; Simeon Guilford, principal assistant-engineer in charge, W. Milnor Roberts, assistant; John B. Ives, contractor. The tunnel was originally 720 feet long, but was shortened to 600 feet in 1858, when it was enlarged in width, under the charge of B. H. Lehman, chief-engineer. Dimensions of original cross-section, 18 feet wide by 15 feet high, about 150 feet at each end arched. The material passed through was an argillaceous slate, and the original total cost (including from 25′ to 30′ of cutting through earth and slate at the east end, and from 35 to 40 feet at the west) was $30,464. The "Conemaugh" and "Grant's Hill" tunnels, on the Western Division of the Pennsylvania Canal, followed in 1828–'30. The next tunnel, and the FIRST RAILROAD TUNNEL in the United States, was the one built by Solomon W. Roberts (subsequently chief-engineer North Pennsylvania Railroad), on the Allegheny Portage Railroad, in Pennsylvania, in 1831–'33. This railroad was built to connect the Central and Western Divisions of the Pennsylvania Canal, and was commenced on April 12th, 1831, completed March 18th, 1834; total length from Hollidaysburg to Johnstown, 36⅔ miles. The tunnel, 901 feet long, was cut through slate 25 feet wide by 21 feet high, arranged for double track, and, like the "Summit Level" Tunnel (see above), arched for the first 150 feet in at either end. The side-walls and arch were of stone 18 inches thick; area of excavation, 525 feet; contract price, $1.47 per cubic yard for excavation, $9.50 per perch (25 cubic feet) for tunnel masonry. The miners were paid $13 per month and found. Prices for outside work: "Common excavation," 9 cents; embankment and overhaul, 14 cents; solid rock, 45 cents; slate, 25 cents; hard-pan, 30 cents; slope-wall, 45 cents.‡

* "London Mechanics' Magazine," vol. xxv., p. 326 (1836).

† For the records of this tunnel, the author is indebted to Messrs. W. Milnor Roberts and B. H. Lehman.

‡ For the records of this tunnel, the author is indebted to Mr. Solomon W. Roberts.

Tunneling, however, of course did not become common until the introduction of steam multiplied railways. The first locomotive * used in this country was the "Stourbridge Lion." It was built by Foster, Rastwick & Co., of Stourbridge, England, and was imported by the Delaware and Hudson Canal Co., who, in 1828, built a road (in Pennsylvania) from their coal mines at Carbondale to the terminus of their canal at Honesdale, and on this road the "Stourbridge Lion" was tried August 8th, 1829. It was found to be too heavy for the roadway, was housed up, and finally taken to pieces and destroyed.†

It seems that the first charter in the United States for a public railroad was granted by the legislature of New Jersey. In 1811, Col. John Stevens, of Hoboken, N. J., presented a memorial to the legislature to authorize a railroad in New Jersey, and in 1815 a law was passed incorporating "The New Jersey Railroad Company," authorizing a road from Trenton to New Brunswick. It was not built, however. In 1820, Col. Stevens built a short road, at Hoboken, as an experiment. The next charter was one granted by the State of Pennsylvania, on March 31st, 1823, to John Stevens and others, to construct a railroad from Philadelphia to Columbia, on the Susquehanna River, a distance of about 80 miles. Among the corporators were Horace Binney and Stephen Girard, of Philadelphia. John Stevens, however, was the master-spirit of the enterprise. Stevens was authorized by the charter to charge tolls on freight not to exceed 7 cents per ton per mile on that going west, and 3½ cents per ton per mile on that going east. The road was "not to rise above an angle of ten degrees with the plane of the horizon," and the charter was to continue in force for ten years. Nothing appears to have been done under this charter; a second charter, which repealed the first, was granted in 1826, incorporating "The Columbia, Lancaster, and Philadelphia Railroad Company." This charter also proved, like its predecessor, to be a dead letter. During the same session of the legislature, some five other railroad companies were incorporated, but none of them were of any particular importance. Finally, in 1828, the Pennsylvania State Canal Commissioners were directed to locate and put under construction a railroad from Philadelphia (*via* Lancaster) to Columbia, and complete the same within two years if practicable. They were also required to examine a route for the Portage Railroad over the Allegheny Mountains, which was subsequently built. Both lines were constructed by the State; they were completed in 1834.

Previously to this time, however, in March, 1827, the legislature of Maryland had granted the charter of the Baltimore and Ohio Railroad Company. This railroad was the first one built and opened in the United States that was authorized by charter to carry on a general business of transportation; the earlier roads (Leiper's in Pennsylvania, and the Quincy Railroad in Massachusetts) having been built for private purposes. The charter of the Baltimore and Ohio Railroad Company was modeled on the old turnpike charters, as at this early date the question had not been decided whether stationary steam-engines or horse-power would be preferable as a means of traction. This was the beginning of the BALTIMORE AND OHIO RAILWAY, the first stone being laid by Chas. Carroll, of Carrollton, one of the signers of the Declaration of Independence. Jonathan Knight was the chief-engineer of the road for the first four years of its existence, with Benjamin H. Latrobe and Henry J. Ranney as principal assistants. Mr. Latrobe subsequently succeeded Mr. Knight as chief, and under his direct supervision it was that the large portion of the road was located and built, the many tunnels driven, and the heavy grades ‡ overcome, that together stand a grand monument to the skill of this

* Dr. Hollister's "History of the Lackawanna Valley," also the "Railway World," 2d Quarto, vol. iii., No. 15, p. 352, and ibid., 10th Quarto Vol., No. 1, p. 1.

† "History of the Pennsylvania Railroad," Wm. B. Sipes, p. 5.

‡ See "The Railroad Gazette," Quarto, vol. vi., No. 471, New York, December 5th, 1874, for an account of the location of the heavy grades on the Baltimore and Ohio Railroad.

distinguished engineer, whose very name is identical with the rise of railroad engineering and tunneling in the United States.

The first division of the road was opened for transportation on the 24th of May, 1830, horses being altogether used for traction.* There being, as yet, no settled mechanical mode of traction, Evan Thomas, during this year, constructed a car with sails, which he called the Æolus; on this car, Baron Krudener, the Russian envoy, made an excursion, resulting soon after in a visit from some Russian experts, who were sent out by the Emperor to examine the system. They engaged the services of Ross Winans for the construction of the Russian railways. Thomas's Æolus, however, was not used on the Baltimore and Ohio Railroad, except experimentally.

About the same time, Peter Cooper built, in Baltimore, the first American locomotive, and with it drew the directors of the road on a trial trip from Baltimore to Ellicott's Mills, at the rate of 18 miles an hour, and in August, 1830, steam-power came into regular use on the line. Cooper's engine was subsequently superseded by one built by Phineas Davis, at York, Pa., in 1831. From this time on, railroad construction advanced more rapidly. In the autumn of 1834, a locomotive built in Boston was taken, *via* the Pennsylvania Canal and Allegheny Portage Railroad, to Johnstown, and during the winter shipped thence to Pittsburg, where it was used as a pattern for the construction of two others; the three were put into regular use on the Portage Railroad during the next year. It is also said † that there were locomotives running on the "Mad River Railroad," out from Sandusky, Ohio, in 1833 or 1834.

The following table ‡ will show the early stages and subsequent increase of railroad construction in the United States:

TABLE 2.

DATE.	MILES IN OPERATION.	INCREASE.	REMARKS.
1830	23	...	It is estimated that these 74,000 miles of road have cost in all about $4,200,-000,000, and that their gross receipts are $500,000,000 per annum. It is further worthy of note that while their construction has extended over a period of forty-five years, about 44,000 miles have been finished within the last fifteen years.
1831	95	72	
1832	229	134	
1833	380	151	
1834	663	283	
1835	1,098	435	
1836	1,273	175	
1837	1,497	224	
1838	1,913	476	
1839	2,302	389	
1840	2,818	516	
1850	9,021	6,203	
1860	30,635	21,614	
1870	52,898	22,263	
to 1876	74,000	22,102	

After the Allegheny Portage Tunnel came the Black Rock Tunnel§ (1835–'37), on the Philadelphia and Reading Railroad. Mr. William H. Wilson who was resident engineer in charge, is now (1882) consulting engineer, Pennsylvania Railroad. This is noticeable as being the first tunnel in the country on which shafts were sunk. The width of tunnel was 19 feet; diameter of shafts, 7 feet; they were sunk outside of the tunnel cross-section, so that the sides of the shafts

* "History of the Baltimore and Ohio Railroad Company," by "A Citizen of Baltimore," 1853.

† W. Milnor Roberts, in the "Railroad Gazette."

‡ "Standard Facts and Figures," Morton & Dumont, New York, 1876; also Poor's "Railway Manual," 1876.

§ The author is indebted to Mr. William H. Wilson, Consulting Engineer Pennsylvania Railroad, for data on this tunnel.

should be tangent to the outer line of the tunnel. These shafts were six in number, located in pairs, 100 feet apart, for the purpose of correcting the errors in alignment that were expected to arise at each shaft, from having to turn a right angle, after bringing the line down.

The Elizabethtown Tunnel,* in Pennsylvania, on the Harrisburg, Portsmouth, Mount Joy and Lancaster Railroad (now Pennsylvania Railroad), built in 1835–'38, W. Milnor Roberts, engineer in charge, was almost contemporaneous with the Black Rock; and following it came the Pulpit Rock Tunnel (1839–'41), on the Philadelphia and Reading Railroad, and the Harper's Ferry (1839) and other Baltimore and Ohio Railroad tunnels, ranging from 1839 on to 1866, amounting to forty-four in all, and all forty-four built by or under the direction of Benjamin H. Latrobe, Esq.

TABLE 3.

SHOWING EARLY TUNNELS OF THE UNITED STATES.

NAMES OF TUNNELS.	LOCATION.	CANAL, C.; RAILROAD, R.	WHEN BUILT.
Auburn.	Schuylkill Navigation (first canal tunnel, and, in fact, the first tunnel in the United States).	C.	1818–'21
Hacklebernie.	Mauch Chunk, Pa. (first mining tunnel in the United States), built by the Lehigh Navigation Co.	....	Commenced 1824; stopped 1827; resumed 1846.
Union C'l or "Summit Level."	Near Lebanon, Pa., on Union Canal.	C.	1824–'26
Conemaugh and Grant's Hill (2 tunnels).	Western Division Pennsylvania Canal.	C.	1827 or 1828 to 1830.
Portage.	On Allegheny Portage R. R., Pa. (first railway tunnel in the United States).	R.	1831–'33
Black Rock.	Philadelphia and Reading R. R.	R.	1835–'37
Elizabethtown.	Harrisburg, Portsmouth, Mt. Joy, and Lancaster R. R. (now (1882) Pennsylvania R. R.).	R.	1835–'38
Sixteen Tunnels.	On Croton Aqueduct, N. Y.	..	1835–'42
Paw-paw.	Chesapeake and Ohio Canal.	C.	1836
Harlem.	New York and Harlem R. R.	R.	1836–'37
Two Tunnels.	Sandy and Beaver Canal, Ohio.	C.	1836–'38
Summit.	Catawissa and Williamsport Branch of Philadelphia and Reading R. R.	R.	1838
Harper's Ferry.	Baltimore and Ohio R. R.	R.	1839–'40
Pulpit Rock.	Philadelphia and Reading R. R.	R.	1839–'41
Doe Gully.	Baltimore and Ohio R. R.	R.	1839–'41
Flat Rock.	Philadelphia and Reading R. R.	R.	1840
Paw-paw.	Baltimore and Ohio R. R.	R.	1840–'41
One Tunnel.	Lehigh and Susquehanna R. R.	R.	1841
" "	Albany and West Stockbridge R. R., N. Y.	R.	1841–'42
Canaan.	Boston and Albany R. R.	R.	1842
Phipps Hill.	Milford Branch of Boston and Albany R. R.	R.	1846
Walpole.	New York and New England R. R.	R.	1848
Greenfield Bridge	Baltimore and Ohio R. R.	R.	1848–'49
White Hall.	Rensselaer and Saratoga R. R. (now (1882) controlled by Delaware and Hudson Canal Co.).	R.	1848–'51
Ten Tunnels.	Hudson River Railway, N. Y. (now (1882) New York Central and Hudson River R. R.).	R.	1848–'51
Everett's.	Baltimore and Ohio R. R.	R.	1849–'50
Kingwood.	" " " "	R.	1849–'52

* W. Milnor Roberts.

The foregoing table shows in concise form the rise and progress of tunnel construction in the United States up to 1850; after which time it is hardly worth while here to distinguish the individual dates.

We have thus, without counting the Hacklebernie Tunnel at Mauch Chunk (as it was simply the first of the early large anthracite coal-mine tunnels), some 52 tunnels in the United States belonging to the first half of the century. Of these, 7 were on canals, 16 on the Croton Aqueduct, and 29 on railways; 48 of them were commenced and completed prior to 1850, and in the second quarter of the century. The Factoryville Tunnel, on the Delaware, Lackawanna and Western Railroad (Pennsylvania), built in 1850–'52, opened tunnel construction in the decade from 1850 to 1860, during which so many railroad tunnels were built as will be seen by consulting the tables in Chapter XXIII. of the author's large work on Tunneling.

From this time on, of course, tunnels multiplied with railroads, and so many were built that it would be tedious to cite them in detail here. It is interesting to note, however, that no canal tunnels have been built in the United States since 1838, and that the decades from 1850-'60 and 1870–'80 have been the most active in railroad-tunnel construction.

And now we have traced the history of tunneling through its ancient record, down past the time it lay in abeyance during the dark and the middle ages, up to its revival by Riquet in the seventeenth century; and thence to the first great advance made in modern times in the art, when Brunel demonstrated the practicability of soft-ground tunneling on a large scale; and we have seen how the number of tunnels was subsequently increased by the introduction of steam and the consequent rapid growth of railways.

The last and grandest step in tunnel construction, however, has been made during the latter half of the present century, by the introduction of high explosives and machine rock-drilling. For nitro-glycerine we are indebted, as we shall see in Chapters II. and III., primarily to Sobrero; but it was Nobel who practically found the key to its application by his invention of exploders; then by his subsequent use of nitro-glycerine in the form of dynamite, he has shown us how to chain and guide the wild forces that once seemed too strong for control. And, last and greatest discovery of all, to Couch, of Philadelphia, we owe the machine rock-drill, or power-drills. He it was, as Chapter V. will show us in detail, who first demonstrated that rock-drills could be driven by mechanical force; and it is a striking fact that this greatest advance in what we have shown to be one of the oldest arts of the old world, rock excavation, should have been made in the new world of America, the land that was discovered only forty-two years after Anne of Lusignan, in 1450, gave the signal for the revival of tunneling in modern times.

It is worthy of note that this art of tunneling has gone in past ages hand in hand with the higher civilization of each era. As a people becomes more civilized, its civilization can be gauged by its progress in tunnel construction, and whatever be the particular motive, the result is always the same. Thus we have seen the religious fanaticism of the Egyptians and Hindus manifested in their grottos and rock-cut temples—the more practical bent of the Assyrians shown in their tunnels and archways. Later, with the Greeks, the religious idea becoming blended with the æsthetic, we find no longer tunnel-building associated exclusively with religion, but the progress of the age is shown in the drainage tunnels of Lake Copäis, the Samos Tunnel, and others. Then with the grand public works of Rome, tunnel-building reached its culmination in ancient times. As civilization went down in darkness, from the decadence of the Roman Empire to the Renaissance, so we see all through the dark ages no evidence of tunnel construction on a large scale, except in the crypts and cloisters of those days. Finally, with modern civilization, we have tunneling in its last and greatest development, and we see that in proportion to the civilization of a people will be found their develop

ment in this art. This is most natural, for, of all branches of construction, it is one of the most difficult. A barbarous people may, perhaps, develop a high degree of perfection in the mere art of open-air building, where stone can be piled on stone, and rafter fitted to rafter, in the light of day; but it takes the energy, knowledge, experience, and skill of an educated and trained class of men to cope with the unknown dangers of the dark depths that are to be invaded by the tunnel-man.

CHAPTER II.

THE HISTORY OF EXPLOSIVE COMPOUNDS, DRILLING, AND BLASTING.

IN order to at all clearly trace up the various steps in the history of explosive compounds, it will be necessary now to go back to their first introduction in the art of war.* Throughout the dark and middle ages, war being the chief incentive to action, inventions

* Most of the early history of blasting in Germany, as given in the following chapter, has been translated directly from Ržiha's "Lehrbuch der Gesammten Tunnelbaukunst," I., p. 39. The English notes have been largely taken from Weale's "Quar. Papers on Engineering," vol. v.

The following are Ržiha's early German authorities:

Sebastian Münster, Cosmographie (1544–1614).
Leonhardt Fronsberger, fünf Bücher vom Kriegsregiment (1555).
Johann Matthesius, Sarepta oder Bergpostill (1562).
M. Cyriacum Spangenberg, Mansfeldsche Chronik (1572).
G. E. Löhneyss, Bericht vom Bergkwerck (1617).
v. Rechenberg, Hermundurorum (1680).
Unterricht vom edlen Bergwerk (1687).
A. v. Schönberg, Berginformation (1693).
Balthasar Rössler, Hell polierter Bergbauspiegel (1700).
C. Hertwig, Vollkommenes Bergbuch (1710).
Hermann Suden's Untersuchung wer das Schiesspulver erfunden hat (1715).
F. E. Bruckmann, Unterirdische Schatzkammer (1730).
Minerapholio, Bergwerkslexikon (1730).
Aug. Bayer, Das geseegnete Markgrafenthum Meissen (1732).
Zedler, Universallexicon (1741–1743).
Kern-Historie aller freien Künste und schönen Wissenschaften (1751).
Allgemeines Magazin der Natur, Kunst und Wissenschaft (1755).
Honemann, Alterthümer des Harzes (1755).
Henning Calvör, H. C. Nachrichten der etc. beim Bergbaue auf dem Oberharze, etc.(1763).
Beckmann, Anleitung zur Technologie (1771).
Temler, Ueber das Alter des Schiesspulvers, in den historischen Abhandlungen der Gesellschaft der Wissenschaften zu Kopenhagen, übersetzt von Heinze, I. B. (1782).
Göttingsches Magazin der Wissenschaften und Litteratur (1783).
Gothaischer Kalender (1783).
Johann Gottfried Hoyer, Geschichte der Kriegswissenschaften (1797).
Holzmann, Hercynisches Archiv (1805).
Meinecke, Ueber das Schiesspulver (1813).
Busch, Handbuch der Erfindungen (1821).
Erdmann's Journal für techn. und öconom. Chemie (1832).
Gätzschmann, Lehre der bergm. Gewinnungsarbeiten (1846).
Neuer Schauplatz der Bergwerkskunde, VII. Theil (1847).

PERIODICALS.

Karsten's Archiv (1828).
v. Moll's Annalen (1801–1805)
Köhler's bergm. Journal.
Gilbert, Annalen der Physik.
Lempe, Magazin für Bergbaukunde (1785–1799).
Gehler's Physikalisches Wörterbuch.

were apt to take their rise from warlike sources, and thence to be subsequently applied in more peaceful pursuits. The following sketch will necessarily be brief, but it is hoped that it will be of interest as showing approximately the successive steps that have gradually led up to the modern improved methods of mining and tunneling, and made possible the great works of the present day, and the probably still greater ones of the near future, the initiatory steps of which have already been taken.

The invention of gunpowder is generally attributed to Berthold Schwartz, a monk of the order of St. Augustine; and the date, as far as it can be fixed, seems to be about 1320, or one hundred and thirty years before the invention of the printing-press. As these early dates, therefore, have to be drawn from old manuscripts, the various accounts of the early introduction of gunpowder into Europe are very conflicting. Thus Sebastian Münster, in the first edition of his Cosmographie (Basel, 1544, p. 333), says, that generally the invention of the "terrible gun," according to tradition and preceding writers, is placed at 1380, but that neither the place where it was discovered nor the name of the inventor is known; that most people, however, assume him to have been a monk. Münster declares it to be his opinion that "the villain who brought upon the earth so injurious a thing does not deserve on earth to have his name remain in the memory of man."

In later editions of Münster's work in 1546, 1598, and 1614, the addition is, however, made that guns were used in naval combats in 1354 by the Danes, and that their discovery was due to a monk, Berthold Schwartz by name, who practiced alchemy. This statement is founded upon a communication received by Münster from Dr. Achilles Gassarus at Augsburg.

The year 1380 (or somewhere near it) is further favored by Flavius Blondus, of Forli, Baptista Saccus or Platina, Polydore Virgil and (probably following them) Æneas Sylvius, Anton Sabellicus, Franz Irenicus, J. Wympfeling, Caspar Hedion, Cochläus, Theodor Bibliander, J. Funccius, Gilbert Genebrard, Nicol Vignier, Heinrich Bunting, Mathäus Dresser, Paul Lange, Peter Albin, Cyriacus Spangenberg, Dubrarius, Stumpf, Alting Alstedt, Buchholzer, Guthberleth,* Mathesius, and others.

Still later dates for the first use of guns are given by Alexander Scultetus (1392 or 1393), Krusius (1390), Achilles Gassarus, in his first works (1393), Anton Possevin (1392), Peter Ramus (1400), and Jacob Faber Stapulensis (about 1400).

The following are for 1354: Hieronymus Ziegler, Heinrich Pantaleon, Andreas Thevet, Claudius Fauchet, Stephan Paschasius, Bullart, Chaterinot, Pontanus, and Athanasius Kirchner. Still others give the following figures: Johann Brodäus (1370), Lucas Wadding (1365), and Felix Malleolus (about 1250). The latter, generally called Meister Hemmerlein (died 1456), about 1444–'50, wrote:

"And yet guns, as far as we know from *writings*, have been invented but within two hundred years." †

The old chroniclers are also by no means unanimous as to the name, occupation, and residence of the inventor; manuscripts definitely deciding this point seem still missing.

Platina says, "Guns were first invented by a German;" Sabellicus, "A German of low descent taught the Venetians to shoot;" Raphael Vollaterranus, "These machines the Venetians first obtained from the Germans;" Egnatius, "Guns were first brought to Venice by the Germans;" Marcus Grapaldus, "The gun has its name from sound (sclopo),‡ and it was,

* Johann Gramm's "Abhandlung vom Schiesspulver im Allgemeinen Magazin der Natur," Kunst & Wissenschaften, V. Theil (1755), p. 145.

† Gramm's "Abhandlung über das Schiesspulver."

‡ Gramm, p. 146.

according to the Germans, invented in Germany." Wympfeling says, "In the year 1380, a gun was invented by the Germans which is generally called a 'Bombarda;'" Johann Aventin, "It should also be noted that Berthold, a German philosopher, a Franciscan learned in sorcery and alchemy, was famed on account of his new invention. . . . . He invented the iron guns;" Scultetus, "The gun is said to have been invented in Germany by a monk;" Achilles Gassarus, "At this period, guns were invented by a German monk;" Brodäus, "It is certain that guns were invented in 1370 by a German monk, Berthold Schwartz;" Athanasius Kirchner, "Powder was, beyond all dispute, invented in 1354 by a German, Berthold Schwartz, born in Goslar; he was a Benedictine monk, and practiced alchemy." Gilbert Genebrard, on the contrary, allows that Berthold was versed in alchemy, but he doubts that he was a monk and a German.

Antonio Cornazzani gives Cologne as the place of the invention; Martin Krusius also writes: "We find that guns were invented by Berthold Schwarzeu or Niger, at Cologne." Others gave Mayence as the place; among them, Dr. Joachim Becher, while Hulderich Mutius and Knipschild give Nuremberg. Johann Lange says the inventor was a Bohemian from the city of Weraw (?) Again, some attribute it to a Burgundian. J. Faber Stapulensis says: "It is uncertain whether the inventor hailed from the Netherlands or from Germany." Alexander of Ferrara, as well as Irenicus, call the inventor Peter; and Joh. Bapt. Pigna, of Ferrara, attributes the invention to the philosopher Peter Libs.

We have seen that Johann Aventin calls Berthold a "Franciscan," and that Athanasius Kirchner says that he was a "Benedictine born in Goslar." Many others state that Berthold Schwartz was a *Franciscan* monk at *Goslar;* others give Freiberg as the place of his birth. Andreas Thevet and Palmuth name the inventor as Constantin Anklitzen, of Freiberg.

Zedler says, in his "Universal Lexicon" (Leipzig, 1743, p. 1923), that the inventor was a monk of Mayence, whose name originally was Constantin Anklitzen, and who was named Berthold Schwartz, after taking holy orders.

This latter opinion, modified so far as to give Berthold's birthplace as Freiberg instead of Mayence (to which view Zedler also accedes in another part of his work), now predominates; and the cognomen Schwartz added to the cloister name Berthold is explained by Barthel's having occupied himself with "black experiments," on account of which he was first popularly known as "Schwartze (black) Barthel," and finally as "Berthold Schwartz." The statement of the Swabian chronicler Krusius is in accordance with this view, where he speaks of "Berthold Niger;" and also the following from an old manuscript (1445) by an unknown author:

"This art was invented by a master, called Niger Bertholdus; he was a Nigermanticus" (sorcerer).*

However the old chroniclers may contradict each other in other points, the frequency with which the monk Berthold Schwartz is named is at least a surety that the name would seem well established, especially as this fact, in connection with the recurring statement that he invented gunpowder in Germany, in the main coincides with the time during which guns were brought into use. So it would seem that the Freiberg statue to Berthold Schwartz rests on as firm a foundation as concurrent history can give.

The great incentive to polemic discussion on Berthold Schwartz has arisen from the fact that several of the old dates, once accepted as authentic, have subsequently been proved erroneous. Thus, those who had adhered firmly to the date 1380 (following the Italian historians, Flavius, Platina, and Polydorus Virgilius, who founded it upon the first great use of guns in the naval encounter between the Venetians and Genoese (1379) at Chioza), subse-

* Hoyer's "Geschichte der Kriegskunst," II. Part (1800), p. 1112.

quently found themselves mistaken, and were forced to admit the year 1354 as of better authority, because it was proved that at that date guns had been used.

Petrarca (1304, died 1374), in his ninety-ninth "Dialogue" (which, according to some, was written in 1344, and to others in 1357 or 1366), mentions guns as then already generally used. Furthermore, it is proved that powder and guns were sold in 1360 by Meister Senger at Nuremberg, and that in the same year the Lübeck "Rathhaus" (City Hall) was burned down in consequence of carelessness on the part of powder manufacturers. In 1356, the citizens of Löwen bought "12 Donnerbüchsen" (thunderguns or bombarda); and in 1365, Duke Albrecht, of Brunswick, defended the city and fortress of Einbeck with a leaden gun against Frederick, Margrave of Meissen and Landgraf of Thuringia.

Johann Rothe, in speaking of this gun in his Thuringian Chronicle, says: "The margrave had machines built which were to be driven to the castle, and then in the castle he had a leaden gun, with which he shot into the works. This was the first gun that was heard of in this country." It is further known that, in 1370, Magnus, Duke of Brunswick, carried guns with him in his army.

In 1377, Richard II., of England,* directed Thomas Norbury to buy of Thomas Rellswold, of London, "two great and less engines called cannon," and 600 stone shot to be sent to the Castle of Brest. In the same year, John Buch, the French admiral, was, says Froissart, in a "ship with three cannon which cast forth darts." These darts were so large and heavy that they did much damage. Some bombards were made to propel shot of extraordinary weight. The renowned Peter Doria had his brains knocked out by a stone bullet which weighed 195 lbs., shot from a bombard called Trevisian.

In the year 1379, it would seem that guns were in general use in Eastern Frisia, for Eggerich Benninga † writes: "As great strife and riot arose in Friesland, the authorities called for the so-called 'Art of Instruments Makers,' and they immediately had guns cast and forged; and they used against their enemies this murderous instrument invented by the devil's chaplain and brought by him into use."

Later historians, having found that guns were used in 1346, at the battle of Crécy; in 1342, at Algeziras; in 1340, on the Salado; that also, in 1344, powder was known at Spandau, and that Augsburg possessed a powder-mill in 1340—the date was again put back, and 1330 adopted; some among them (B. Meyer, for instance) were not even satisfied with that date, because it was said that, in 1334, Margrave Este had guns, and further, that, in 1326, they were used at Martos. Finally, going still further back, 1320 was therefore finally assumed.

Now, although, according to these data, we are decidedly uncertain as to the exact time of Berthold's invention, and probably shall remain so, there is no doubt of the main fact that long, long before he applied or invented in Germany what we know as gunpowder, explosive mixtures of various kinds were known and used far back in the dark ages; and if we go to the East, we find gunpowder itself in use among the Chinese before the Christian era.

The oldest statement in manuscript, on the preparation of explosive compounds, is said to have been made (according to Meyer) by Julius Africanus, in the year 215. According to the same authority (Meyer), the Arabs, in 690, when besieging Mecca, hurled balls of fire, by the use of naphtha, upon the roof of the Caaba, and the soldiers of the Emperor Leo are also said to have used these balls of fire in 811.

In 668, the Greek Callinicus, of Heliopolis, is said to have communicated to Constantine IV. the ingredients of this mixture, termed by the ancients, "naphtha," and now known as "Greek fire." It is well known that it enabled the Byzantines to withstand the Crescent

* Weale's "Quar. Paper on Engineering," vol. v.

† Gramm's "Allgemeines Magazin, etc.," V. Part, p. 212.

for centuries; and Hoyer directly says that fire was hurled at the enemy, and that balls of earthenware, filled with this composition, were fired from tubes; that the mixture was by no means fluid, and that it most probably consisted of the ingredients of our powder mixed with resin and petroleum. Later historians and engineers do not go to such lengths, but are satisfied in assuming that Greek fire was probably hurled from a slinging machine of some kind. It should be noted that the older statements as to the use of guns are frequently looked upon as arising from a misconception of the word "bombarda," and that the earlier guns were in fact balistæ from which were hurled fiery bodies.

The oldest authentic statement on gunpowder is attributed, according to Jebb,* to Marcus Gracchus; a manuscript bearing his name is said to exist at Oxford, which describes † a mixture of 1 lb. sulphur, 2 lbs. charcoal, and 6 lbs. saltpetre, as known in 846. Later, Meyer writes that, in 1073, King Salamo, of Hungary, used guns at Belgrade; and that, in 1098, the Greeks are said to have had them in a naval encounter with the Pisans. According to Hoyer, Peter Mexica quotes from the history of Bishop Peter, of Leon, to the effect that, in a naval fight, the ships of the King of Tunis, at Toledo, about 1085, had certain guns, "bombardis," from which they shot "fiery thunder."

An old chronicle states that when Richard I., of England, was off Cyprus, in 1191, with his fleet, he fell in with and "conquered a mighty argofy," well stored with provisions, arms, and other munitions of war, among which were "abundant phials of Greek fire, and three hundred combuftible ferpents," or, as old Speed reads them, "fireworks and barrells or cages of venomous ferpents." These "combuftible ferpents" were probably of the kind described by Joinville, and seem to have been a kind of rocket.

It is further said that the Tartars, in 1232, used guns against the Chinese; and (according to Hoyer), in 1247, Don Jayme threw large glowing balls when besieging Valencia. In 1247, Seville and, in 1249, Damietta were defended against Louis the Holy with fiery balls which were the terror of the Crusaders.

Roger Bacon (died 1284) speaks of the destructive effects of saltpetre compounds as then a well-known fact, saying that from saltpetre and other substances terrible thunder and lightning may be produced.‡

John Mathäus de Luna, in his work "De Rerum Inventoribus," attributes the first invention of guns and muskets (bombardam, bombardulam et scolpum manualem) to the learned monk, Albert Magnus (died 1280, at Cologne). According to the chronicle of Hieron. Peez, of Leoben, Sultan Melech Seraph, in 1290, used three hundred machines which incessantly threw Greek fire, while besieging Ptolemais.

In 1308, guns are spoken of before Gibraltar; 1311, muskets before Brescia; and, in 1312, guns were used by the Arabs before Baza. In the Amberg Arsenal, there is said to be a gun bearing the date 1303. From this time on, statements grow more frequent and reliable on the subject, and we come to the period before considered, in which Berthold Schwartz seems to have applied or invented the substance approximating in nature to our modern gunpowder. Though the data given admit of discussion as to whether the "guns" used before the Moorish wars were truly guns in our sense of the word, or perhaps only a name for the fiery balls hurled by the old slinging machines, there seems to be no doubt that a mixture containing a large percentage of saltpetre was known at the time of the Byzantines, and that our gunpowder came from the East to Europe. It is certain that, in the beginning of the fourteenth century, the existence of such a mixture was widely known in Germany on account

* Roger Bacon, Opus Majus, D. Sam. Jebb, London, 1733.

† Hoyer, p. 8.

‡ Roger Bacon, Opus Majus, p. 474. Hoyer, p. 37, and additions, p. 1 in vol. I.

of the terrible properties with which it was accredited; and it would seem a fair assumption to make, that the matter struck one of the learned monks who at that time alone followed scientific pursuits; that, on investigation, he finally prepared and made known an explosive compound of a more perfect kind than any of the former compounds. This opinion would seem to be strengthened by the circumstance that the old manuscripts preserved in the monasteries directly claimed that "Barthel" knew of Roger Bacon's works,* and the opinion is further backed by the many concurrent sources tending to fix Germany as the locality from which the discovery emanated.

That "Barthel's" invention, if it be accepted as his at all, must at least be placed at 1320, would seem confirmed by the occurrences given in the table at the end of this chapter, covering from 1334 to 1344, chiefly concerning Middle Europe. We see from this table, in general, that Germany advanced steadily in the preparation of powder and of guns; and as, at that time, German mercenaries served in the Italian wars, the introduction of guns from Germany to Italy, for instance, perhaps at Chioza, in 1379, is the more easily explained, as at that time the "Hansa" (Hanseatic League) flourished.

In the beginning, powder was prepared by hand; later on, mills were introduced. The first true powder-mill in Germany, as has been already noted, is said to have been in operation at Augsburg in 1340, and in 1360 the manufacture of powder must certainly have been going on, for, as we have also seen, the burning down of the Lübeck Rathhaus (City Hall) was attributed to it.

Later, stamp-mills were introduced in place of the early millstones, between which the powder had been ground, the latter being found too dangerous. One Harscher owned a stamp-mill near Nuremberg, in 1435; and in the latter half of the fifteenth century, these mills were built in almost all European countries.

In the year 1692, we are told that there were 22 powder-mills with 829 stamps in France alone. The first Silesian powder-mill was built by Pollak in 1536. The first rotary mill is said to have been built in 1754 by Ferri, at Essone, in France, and, in the same year, Karl Knutberg, in Sweden, describes a similar arrangement—*i. e.*, rotation of wooden wheels around a vertical axis. In 1756, Ferri made a new arrangement, rejected again however, in which heavy iron rolls were drawn forward and backward over a horizontal plate.

In the beginning, gunpowder was ground to a powder more or less fine. It was soon perceived that this formed dust, attracted moisture, and was easily caked. In consequence, graining was decided on, and this was first done in France in 1525. Before drying, it was pressed through a screen, and the different sizes were distinguished according to the grain.

Of course, as the use of gunpowder became general, it attracted more or less of royal attention. Thus, in 1439, we see Archbishop Günther, of Magdeburg, making the preparation of wall saltpetre a royal prerogative; and, in 1520, Gustavus I., of Sweden, decreed that the soil of cemeteries should be leached to produce saltpetre. In 1561, there were 22 saltpetre works in Sweden, and there are notes on the subject in Erker's "Beschreibung Allerfürnemisten mineralischen Ertz und Bergkwercksarten," page 125 *b*, Prague, 1574.

In 1602, it was ascertained how much saltpetre was to be had from a certain amount of earth in Sweden. In 1605, a decree by Henry IV., of France, was published on the manufacture and refining of saltpetre, and, in 1642, the delivery of a certain quantity of saltpetre was made a tax in Sweden. In England, in 1626,† the manufacture of saltpetre, says the king (Charles I.) had hitherto produced much trouble and grievance to the lieges, "by occafioning the digging up the floors of their dove-cotes, dwelling-houfes, and out-houfes; and had alfo occafioned great

* "Kernhistorie aller freien Künste, etc.," p. 572. † Weale's "Quar. Papers on Engineering," vol. v.

charge to the faltpetre men for removing their liquors, tubbes, and other inftruments, and carrying them from place to place, but now divers compounds of faltpetre can be extracted by other methods, for which Sir John Brooke and Thomas Ruffel, Efq., have received letters-patent."

To encourage so laudable a project, "all our loving fubjects," continues his majesty, "inhabiting within every city, town, or village, after notice given to them refpectively, fhall carefully and conftantly keep and preferve, in fome convenient veffels or receptacles fit for that purpofe, all the urine of man during the whole year, and all the ftale of beafts which they can fave and gather together whilft their beafts are in their ftables and ftalls, and that they be careful to ufe the beft means of gathering together and preferving the urine and ftale, without any mixture of water or other thing put therein. Which our commandment and royal pleafure, being fo eafy to be obferved, and fo neceffary for the public fervice of us and our people, that if any perfon be remis thereof we fhall efteem all fuch perfons contemptuous and ill affected both to our perfon and eftate, and are refolved to proceed to the punifhment of that offender with what feverity we may."

1630. Patent granted in England to David Ramseye, "to multiply and make faltpetre in an open field, in fower acres of ground, fufficient to ferve all our dominions."

In 1755, a premium of 4000 livres (pounds) was offered for the best work on the production of saltpetre, which premium was later on doubled.

In 1788, Lowiz, as well as Godolin, rendered great services in the purification of saltpetre, the latter introducing the refining of large quantities. As late as the second half of the seventeenth century, the proportion of the ingredients of gunpowder was determined solely by custom. De la Hire, Papin, Bernoulli, Huygens, Anderson, and Bigot de Morogues are among the first investigators who looked into the subject, though the teachings of Galileo and Toricelli perhaps served as their foundation.

The ingredients of gunpowder were at that time:

In France, 75^5 saltpetre, 12^5 sul., and 12^5 C.
" Spain, 78 " 13 " " 11 "

In 1742, Robins appeared with his theory of the ignition of gunpowder. However, Robins and, after him, Maffei, Vandelle, De Saluce, D'Arcy, Lambert, Nollet, and Antoni only took into consideration the quantity and force of expansion of the gases, without chemically examining them. Mayow (1669), Stahl (1720), Priestley (1774), and Scheele (1778), were the ones who chiefly cast light upon the chemical phenomena involved in the burning of gunpowder, and Ingenhouss, Foureroy, Berthollet, Achard, and Gren studied the proportions of the ingredients to be taken, as well as the phenomenon of burning. The greatest achievements in this province we owe to Lavoisier (born 1743, died 1794), who, in consequence of experiments on the burning of powder made in 1777 to 1778, was enabled to shape his famous theory. Experiments made in France resulted in a mixture of

16 parts nitrate of potash,
3 " carbon,
1 part sulphur,

for the strongest powder; the other countries in general adopted this proportion, though, of course, variations were made according to the special object in view, and the character of the ingredients used. Don Barcelo (1784), Minando (1789), Baine (1789), and Wurzer (1792), attempted to heighten the effect of powder by admixing other substances. As we come up to the questions involved in to-day's consideration of explosive compounds, we must remember that firing by electricity was mooted long since, though it has only lately come into general use. It was proposed by Franklin in 1751, and by Priestley in 1767. (See "Quarterly Journal of the Chemical Society of London," 1862, vol. xiv., p. 165.)

Moses Shaw, of New York, first practically carried the idea into effect in 1829, and, on June 3d, 1830, he took out a patent "for blowing off very large masses of rock by making a number of simultaneous explosions; to effect which a number of holes are to be bored, which may stand around in a circle, and be so inclined as to point to one common focus. A priming compounded of fulminating silver and gunpowder is to be ignited by a shock from the electrical machine, there being a suitable arrangement of wires for that purpose." ("Journal of the Franklin Institute," Philadelphia, October, 1830. See also Silliman's Journal, vol. xvi., p. 372.)

Further, according to the above reference in the "Journal of the Franklin Institute," in the words of the patent, it is claimed for the process that "its superiority and usefulness consist in enabling operators to burst off large masses of rock, etc., by igniting a number of charges at the same instant."

In 1832, Braconnet dissolved starch in nitric acid, obtaining a white, combustible substance he called xyloidine. In 1838, Pelouze showed the action of nitric acid on wood fibre (see "London Chemical News," No. 234, "On the Chemical History and Application of Gun-Cotton"); and, in 1846, Schoenbein, with his discovery of gun-cotton, foreshadowed the revolution that has come in mining and tunneling. Sobrero followed him in 1847 with nitro-glycerine. Gun-cotton was shown by Schoenbein at the British Association, September 1st, 1846. His discovery immediately led to many other similar compounds being made. A description of nitro-sugar was published by Lewis Thompson, December 8th, 1846 ("Pharmaceutical Transactions," 1846–'47, vol. vi., p. 349). In the "Comptes Rendus de l'Académie des Sciences," vol. xxiv., Session of January 25th, 1847, there is a communication from M. Pelouze, through Messrs. Florés, Demonte, and Ménard, announcing that mannite and the various species of sugar and gum furnish compounds analogous to pyroxyline, by the action of nitric acid. Sobrero, in a subsequent letter to Pelouze, noticing the above communication, claimed that the idea of producing fulminates from sugar and analogous compounds had been realized "long since" by himself—*i. e.*, prior to Pelouze's experiments. In the same letter, Sobrero announces his discovery of nitro-glycerine.

Owing, however, to the early fear that was manifested in their application, these explosives did not come into general use until 1860. In 1862, gun-cotton was again tried in England, and, in 1863, Nobel, of Hamburg, began to bring nitro-glycerine into general use as a blasting agent. In 1867, he applied it in the form of dynamite, by mixing it with silicious earth; since that time the use of nitro-glycerine has become general throughout the world, it being used both in the pure, also as dynamite proper, and in a multitude of other forms which will be found described more particularly in Chapter III., where also will be found noted various other compounds suggested of late years as substitutes for gunpowder.

The Introduction of Blasting into Mining.

So much for the history proper of the discovery and early knowledge of explosive compounds; we now come to the history of their early practical application. We have seen how the knowledge of explosive compounds was applied to the art of war, and that in warfare these compounds were used long before Berthold Schwartz finally invented what we now distinctively know as gunpowder. As the date of 1320 seems generally adopted for the invention of this substance in Germany, by a German monk, it seems strange that there should nevertheless be a tradition that is credited by some, that, as early as 1130, powder was used for blasting rock in the Rammelsberg at Goslar, and there is also a tradition that Pfalzgraf Heinrich, son of Heinrich der Löwe, destroyed the walls of the Saracen castle Choruntum, near Tyre, with the aid of powder, in 1197.*

* "Gothaischer Kalender," 1783, p. 150; Beckmann's "Technologie," 1796, p. 522; "Zugabe zu den Göttingschen Gelehrten-Anzeigen," 1782, p. 445; "Technologie," by Funke, 1812, p. 382; "Haupt Chronologische Uebersicht, etc.," 1861.

Historians, however, emphatically combat these statements. Especially Von Veltheim, in the "Göttingen Magazin für Wissenshaft und Literatur," 1783, p. 658, etc., and Holzmann, "Hercynisches Archiv," 1805, p. 658, show that these statements most probably are the results of faulty translations, and probably refer to the use of the fire system of excavation.

Those advocating these earlier dates contend that gunpowder may have been introduced originally through the Deutschritter (German knights), and the Hanseatic League, or through the Moors in Spain.*

The improbability of there being any truth in these traditions is shown from the fact that in the old Rammelsberg chroniclers of that date, the application of gunpowder is nowhere spoken of; further, as to the legend of blowing up the Saracen castle, old authors directly mention that the walls of the castle near Tyre were destroyed by burning, and R. L. Honemann says, on the authority of Helmoldus, Meibom, and Heineccius, that Pfalzgraf Heinrich employed the miners he brought with him from Goslar to the East to undermine the mountain, and that, in excavating, they lit a fire, according to home custom, and thus shook the walls of the castle.

Another plan used in these primitive days was to dig under the walls and support the ceilings of the galleries on posts, which were set fire to when the mine was completed, and the supports being burnt, the walls above fell down.

So much for the history of the early invention of explosive compounds; now, let us again turn back, and trace up the application of gunpowder proper, as we know it, in its early application, in blowing up mines in warfare, and, later, in true rock-blasting.

The first decisive note on the use of gunpowder for blasting is placed (according to Meyer) in the year 1397, at Merat, where a mine was blown up in military operations. Later are noted the mines before Belgrade in 1441, and the ones tried by Knut Posson, commandant of Wiborg, in 1495. By many the introduction of powder-mines in military operations is attributed to the Genoese engineer, Francesco di Giorgio, from Siena, toward the close of the fifteenth century. The real introduction of mines in warfare on a large scale, however, is generally attributed to Pedro Navarro, who made his first attempt at Serezanalla. In 1500, he was more successful before St. Giorgio in Cefalonia. In 1503, mines were used in the siege of Neapolitan castles, and, in 1523, before Milan; and Hoyer expressly states that, as the art was not well known, they met with ill success at Milan, and that therefore, at Verona and at St. Paul, they returned to the old method of undermining and heating the rock to crack and shake it.

Meantime the Turks were more skilful, using powder-mines with great success at Rhodes in 1523, and before Vienna in 1529; and during the crusades, miners are said to have accompanied the troops.

Later, Mathesius writes in his Bergpostill, p. 23: "The great generals always liked to carry miners with them. . . . . Thus, in the siege of Vienna, miners are said to have driven against the Turkish sappers, and to have met them and captured from them some casks of powder. In order to find out where the Turks were with their gallery, they are said to have placed a drum upon the earth, and at night, when it reverberated, they knew where to sink down."

Honemann, p. 136, also says that Tilly had 300 miners brought from the Harz during the siege of Göttingen, and employed them in mining.

In his "Geschichte der Kriegskunst," Hoyer (I., p. 525) distinctly mentions that, at the time of the Thirty Years' War, companies of sappers and miners existed in the various armies, the Swedes only excepted, whose Dalekarliers were, to a man, miners, and who therefore needed no special companies. The same author mentions in vol. ii., p. 129, that the Turks

* Bauer, III., p. 521 (1837).

also had especial miners at the siege of Vienna, whom they called Lagumgys, chosen from Armenians, Greeks, and Bosnians, accustomed to work in the mines.

From these data, it is evident that the use of gunpowder as a disruptive agent, as well as its application in fiery projectiles, preceded its use in ordinary mining and blasting by drill-holes, and it seems probable that it was first usefully applied in mining in moving large masses where a bearing could be obtained; somewhat on the same principle as in military engineering.

Thus, it is mentioned in the "Neuen Schauplatz der Bergwerkskunde," part vii., p. 30 (unfortunately without giving the authority), that, as early as the fifteenth and sixteenth centuries, powder was used in quarries.

Hoyer says, in vol. i., p. 222, that, according to Thom. de Morla, Estaran de Garibay and Paul Jovius (the latter a friend of Pedro Navarro), Pedro Navarro (1500) had even then discovered the elementary principles of drill-hole blasting long before it had been introduced in mining.

Richter's note in his "Bergbaukunde," that "Mathesius mentions in the XII. miner's sermon of his Sarepta, that at that time (1562) gunpowder was used for blasting above ground," has also been pointed out as a proof of the early use of drilling and blasting. This quotation, however, does not seem justified in supporting the position, because the passage alluded to points evidently to mines as used in warfare, and not simply to drilling and blasting.

It reads in the Nuremberg edition of 1564, p. cxcv.: "And here the text mentions the fire with which you miners do excavate and overcome the rock, as Hannibal broke a way over the Runtzefall; lighting fire against the rock and cooling the hot rock with vinegar, as our warriors do now lift and blast rock and walls with gunpowder and break it with their tools."

There is also a reference to blasting in Bruckmann's "Unterirdische Schatzkammer," p. 390; but none of these early notes are sufficiently explicit or positive to establish that drilling and blasting is clearly meant.

The oldest positive records on blasting and drilling date from 1613, with the distinct mention of its use in a mine.

Gätschmann cites an account of ore raised in the quarter Trinitas, Anno 1715, where, on the occasion of the death of a boss killed by a shot in the Altväter Fundgrube, the following note was made:

"Drilling and blasting was invented in 1613, by Martin Weigel, chief mining boss at Freiberg; at first wooden plugs were used to tamp the holes, but for thirty years past (*i. e.*, since about 1685) this has been more safely and easily done with clay. Now, also, at various places, certain small hand-drills have been introduced, by which the miners can very advantageously gain upon hard rock."

This year (1613), as noting the introduction of drilling and blasting, is confirmed by a note to Rössler's "Hellpoliertem Bergbauspiegel," discovered by Berghauptmann Treiesleben, and published by Gätzschmann, p. 329, where it is said that, according to a report in manuscript, dated October 30th, 1613, by Martin Weigel, Oberbergmeister to his "Churfürstliche (Electoral) Highness" of Saxony, he claimed to be the inventor of drills, and had therefore applied to his "Churfürstliche Highness" for the grant of a privilege.

Finally, also, Augustus Bayer, in his work, "Das gesegnete Markgrafenthum Meissen," published 1732, says of this date, 1613: "In this year, Martin Weigold* invented the drilling of rock with a plug insertion."

* Weigel, not Weigold, born 1555, at Schwarzenberg, in Saxony, when twelve years old, was, according to custom, sent to the Harz mines to work; he thence returned to Saxony, and held various positions: in 1582, Steiger in Schneeberg; 1590, Markscheider; 1593, Berggeschworner; 1595, Bergmeister in Annaberg; 1597, Bergverwalter, and, finally, in 1601, Oberbergmeister. Died 1618. (Ržiha following Calvör and Gätzschmann.)

However, all the old mining authors are not unanimous in designating the year 1613 as the one in which the invention of drilling and blasting appeared; sometimes a later date is given.

For instance, Balthasar Rössler (1700) says, in his excellent work, vol. iii., chap. 5, § 3, p. 62: "This blasting came to Germany from Hungary in 1627, and was used at Grösslass; then it was brought to the Harz, from whence it spread in all directions. Though it was not liked in some places because the destruction of the mine was feared, it has done much service; many mines have been reopened and made valuable which were not workable before by hand, because too much time was lost and too many tools used up; now there is a saving both in tools and time."

Honemann says on this subject (§ 282, p. 174), that "in the year 1632, some one, whose name is unknown, showed (in the Harz) how to facilitate mining by drilling and blasting."

Henning Calvör, in his work "Nachrichten über das Berg- und Maschinenwesen am Harze, etc.," in addition to other interesting historical notes, vol. ii., p. 21, gives, with Bayer, 1613 as the correct date, and he adds that he could make nothing out of Rössler's account, or of Christian Melzer's, in his "Stadt & Berg-Chronik vom Schneeberg" (1716), where he (Melzer), p. 197, says that "drills came to Meissen from the Harz."

Calvör also writes that blasting was used, 1632, in Clausthal, but that expenses for powder do not appear in the weekly bills before 1634.

In his letters, "Ueber mineralogische Gegenstände," Born says, that in a mine near Düllen, not far from Schemnitz, in Hungary, he saw large bore-holes in the year 1637 cut into the rock.

That before 1613, experiments made with blasting, if made at all, were but exceptional and attracted no general attention, seems proved by Agricola, Mathesius, Löhneyss, and the chroniclers of the Rammelsberg.

The first, Agricola, the oldest author on German mining, only mentions, like Mathesius, the great difficulty of working hard rock, and speaks of no trial of blasting with powder in mines. Figs. 3 and 4 are cuts from Agricola showing the fire-setting system. The chroniclers of the Rammelsberg mine, also Hacke, Rawen, Honemann, and Bruckmann, speak of how, under Duke Henry the Younger, in 1552, the deep Meissner-Stollen (Meissen Adit) was reopened, and the rock grew so hard that the work had to be abandoned.

As Löhneyss's "Bericht vom Bergkwerck" appeared in 1617, or four years after Weigel's first trial of drilling and blasting, it would certainly seem that even then blasting had not been introduced in the Harz mines as of general notoriety, for Löhneyss has nothing on the subject. On page 10, he says: "The tools with which they work in the mines are: large hammer, small hammer, wedge, shovel, pick, and gad; these are all the tools with which ore is gotten." And page 55: "In soft lodes they work with a pick, but in the hard ones with wedge and hammer; . . . . in the very hard ones, fires are built."

These quotations exhaust the most eminent old German mining authors. Whatever may have been the data of the first trials with drilling and blasting, it is certain that by 1634 to 1644 the use of powder had become more general, for, in 1634, the Harz mining accounts show expenses for powder, and it is said that there are even traces of drill-holes at Düllen dating from the year 1637, which, no doubt on account of their novelty, were then marked with the date; it is further established that blasting was introduced into the Hohe Birke mine in the Freiberg district about 1643. Now, assuming that Martin Weigel made his first experiments in blasting in 1613, as we have seen that Berthold Schwartz's discovery dates from 1320, it would appear that some two hundred and ninety-three years elapsed, after its original discovery, before gunpowder was applied in mining, and some thirty years more passed after Weigel's application of it, before it was found in general use in the German

mines. Even after its use had become generally known, it would appear that the progress toward the adoption of blasting, as the chief means of rock excavation, was exceedingly slow. In the year 1693, the total quantity of powder used in Germany is said to have only amounted to 19 cwts. In 1644, fifty-seven shots only were fired in the mine, Hohe Birke using 117 lbs. of powder. In 1675, thirty-one years later, only 3 cwts. were used in this mine, while in the same year (1675) the consumption of powder in the whole Freiberg region had risen to but 100 cwt.* At this period, blasting is very generally mentioned in technical literature; as in Rechenberg's "Hermundurorum" (1680); Andrea Bayer (1681), in his "Liederbuch;" "Unterricht vom edlen Bergwerk" (1687); in Schönberg's "Berginformation" (1693); and in Balthasar Rössler's "Bergbauspiegel" (1700), etc.

Counting from 1613, it is said that fifty-seven years elapsed before blasting was taken to England by German miners; and one hundred and eleven years before it was taken by them to Sweden. For seventy-two years, bore-holes were stopped with a wooden plug before it was discovered that tamping with clay or any soft material sufficed. Eighty-three years passed by before narrow bore-holes were used; for one hundred and seven years, boring was done by several hammers on one drill, and for one hundred and twelve years blasting was only auxiliary work, cuts being made into the rock before the face was blasted out. Again, one hundred and thirty-four years elapsed before it was officially decreed in the Freiberg region that blasting should be used in hard rock instead of pick and gad work; one hundred and seventy-seven years are said to have passed before the advantage of leaving a hollow space was mooted; one hundred and seventy-eight years before the use of sand-tamping was found out; two hundred and eighteen years rolled by before Bickford, in England, invented the safety-fuse, and it is notable (as we have before seen) that in the same year (1831) the first patent for the simultaneous blasting of a number of holes by electricity was taken out by Moses Shaw, of New York. Further, two hundred and thirty-three to two hundred and thirty-four years elapsed before Schönbein and Sobrero inaugurated the era of high explosives by the discovery of gun-cotton and nitro-glycerine; two hundred and thirty-six years before Couch, of Philadelphia, made the first percussion rock-drill; and, finally, two hundred and forty-eight years after Weigel's day—*i. e.*, in 1861—machine rock-drilling was finally triumphantly established at Mont Cenis.

Drilling and blasting, of course, in its early days, had to contend against the opposition always incidental to the introduction of a new practice. Until 1696, large holes of from 2 to 2½ inches diameter were always drilled, and, as a rule, they were put about 40 inches deep. This depth, and the fact that not until 1673 in Saxony (?) and 1720 in the Harz, was one-hand drilling used, shows that at least, in the narrow adits and headings, shots must often have been disadvantageously "set." The great width of the holes, the want of skill in drilling, and the use of insufficient tools, which drilled poorly and required frequent sharpening, all tended to render the new process a costly one. Until 1749, crown and cone drills Figs. 17(*a*) and 17(*b*), were used, as the chisel-bit drills were only then introduced. The drilling of a hole of the above dimensions, we are told, cost 16 g. Gr. 3 Pf. in the Freiberg region, in 1643; the firing of the shot was especially paid for at a cost of 3 g. Gr.

Now, as the wages for a shift of 8 hours were, at the time, 4⅜ g. Gr., assuming that three men, drilling a 40-inch hole, required 11 to 12 hours' work, it cost, with 2 lbs. of powder (at 8 to 9 g. Gr.), in all (with or without extra expenses?) 36 g. Gr. 3 Pf., or more than 1½ Rthlr., a sum which in those days represented considerably more than it does now. It is also of interest to note that at that time the charge of a hole had already been fixed at one third of its depth; for, assuming 1 cubic inch of powder equal to 1 oz. old weight, then the 2 lbs.

* In 1843, the consumption was 2429¼ cwt.

charge required 64 cubic inches, corresponding with a diameter of the hole of 2½ to 13 inches space occupied by powder, or one third of the depth.

Other reasons for the slow introduction of blasting were, doubtless, the danger of the work, so much greater in the early stages of the arts, when all was experiment, and no experience could be brought to bear; also the cheapness of wood at that time was a strong argument in favor of the old fire-setting system; and the argument which we have seen raised in modern times against the newer explosives, that the gases generated would be injurious to health, must have been urged with tenfold force in the early beginning. Also, there was the natural apprehension that these powerful explosions would endanger and shake all the adjoining workings.

Now, to recapitulate briefly, we have seen that at first wide holes were deemed essential in all cases; that subsequent practice showed that greater economy and more work could be obtained by varying the diameter of the hole according to its location, and that in time the old wooden plugs were superseded by clay-tamping. These were the gradual practical developments of a century of mining; but, meantime, experiments on a large scale had been going on in military engineering, inaugurated in 1686 by Vauban at Douay, and (according to Migrini) at Tournay. Controversies with Belidor and others arose over the results obtained. La Fere, in 1725, obtained other results, and D'Abouville threw further light on the subject in 1729. Further experiments were made at Turmel and Antoniazzi in 1739, by Belidor, and, finally, in 1753, under the direction of the Duke of Belle Isle, a new set of trials were made, and the existence of Belidor's "globe of compression" confirmed. This latter is the name applied to the effect produced when the charge is lodged so deep underground that its explosion is not perceptible on the surface, but nevertheless shakes the ground all around and destroys the hostile mines in the neighborhood. Le Febre again confirmed the existence of "globes of compression" in a set of experiments in 1754 near Potsdam, and they were actually used by him in 1762 in besieging Schweidnitz.

Opinions did not agree also as to the shape of the cavity produced by an explosion. Müller, who was present during the experiments of La Fere, contended that it was a truncated paraboloid, while Geuss opposed this, and measured the effect simply by straight lines.

Another point also was raised, which was especially advocated by Ingerhouss and Pinto; they maintained that a charge should not be rammed closely, but that a hollow space should be left to allow the admixture of atmospheric air with the gases at the very moment of ignition. Finally came Lavoisier, who, we have seen, finally settled the chemical questions involved.

To revert to drilling and blasting in mining proper, the first "theory on blasting" seems to have been advanced by Dr. Baader (his principles were published in 1792, gathered from experiments made by him, in company with Berggeschworener Wentzel, in the Freiberg region). Although Baader's opinions were by no means universally adopted, they nevertheless gave rise to extensive experiments, which (probably from having been made in different materials under differing circumstances) it seems differed essentially from Baader's results, and gave rise to various controversies.

These attempts at "improvements" bore on the various questions of improved methods of manufacturing powder, on enlarging the powder-chamber in the bore-hole, on the mode of tamping, the mode of firing, and the best method of drilling holes. Some advocated the admixture of other substances with the powder; others sought to gain the greatest effect of a shot from better tamping; sand was tried, and plugs of different substances. Here also, as in military engineering, the hollow-space theory was mooted, and the advocates of the theory differed as to whether the space should be left below the charge, or in its midst, or directly above it.

Others introduced wedges and cones into the tamping in order to tighten it; and some strove to obtain as large a surface of attack for the force of powder as possible, by widening the holes at the bottom by the use of oxy-hydrogen gas, or by using corrosive acids in calcareous rocks, or by expanding borers intended to enlarge the hole at the bottom (this idea is by no means dormant at the present day, as shown by Figs. 51 to 53). Then came patents for mechanical hand-drills, and, finally, machine-drilling and the use of high explosives.

CHRONOLOGICAL TABLE.*

CONTAINING THE MOST IMPORTANT EVENTS CONCERNING EXPLOSIVE COMPOUNDS, DRILLING AND BLASTING.

A.D.

80.—The Chinese are said to have known of powder prior to this date.

215.—Julius Africanus is said to have described the preparation of powder.

668.—Callinicus, of Heliopolis, communicated the knowledge of Greek fire to the Byzantines.

690.—According to Elmacinus, Hagiagäus is said to have thrown balls upon the roof of the Caaba by means of "naphtha" (Greek fire), and to have crushed and ignited it.

811.—Emperor Leo is said to have had fire-arms of some kind.

846.—Marcus Gracchus (in a work preserved in the University of Oxford) records an explosive mixture of one pound of sulphur, two pounds of charcoal, and six pounds of saltpetre. (S. Jebb, London, 1733.)

880.—Leo, the philosopher, made rockets for the army of the Eastern Roman Empire.

1085.—In a sea-fight near Toledo, "fiery thunder" was shot from the ships of the King of Tunis. (Peter Mexica, on authority of Bishop Peter of Leon.)

1098.—In a sea-fight with the Pisans, the Greeks used some species of fire-arms.

1130.—At this time, rock is said to have been blasted with powder in the Rammelsberg, near Goslar (?). (This tradition is not well authenticated and is much questioned.)

1153.—A silver mine worked in Cumberland (England) by King David. (Weale's "Quar. Papers on England," vol. 5. Probably worked by pick and gad, or equivalents: perhaps fire system: certainly no explosive used.)

1191.—Richard I., of England, conquered off Cyprus a "mighty argofy," . . . . . "ftored with abundant phials of Greek fire and two hundred combuftible ferpents."

1232.—The Tartars used fire-arms.

1238.—Don Jayme used "large fire-balls which burst" at the siege of Valencia.

1247.—Seville defended with fiery projectiles.

1250.—The Arabs used an explosive compound before Damietta.

1280.—Albert Magnus, the German preaching friar, who was of the lineage of the Counts of Ballstadt of Laningen, described powder, and is said to have known of muskets. He died at this date.

1284.—Roger Bacon (died 1284) speaks of the components of powder as already known (De Militate Magiæ).

* The ground-work of this table was originally compiled by Mr. Franz Ržiha. (See vol. i., p. 58, of his "Lehrbuch der Gesammten Tunnelbaukunst," 1864.) The author of this work has translated Mr. Rziha's notes, and also supplemented the table with English, American, and other data.

1296.—The miners in Devonshire were either too few in number or not sufficiently skillful, for, in this year, 337 miners were brought from the wapentake of the Peak, in Derbyshire, to Martinstowe, who fined and cast into bars 704 pounds weight of silver. In the next year, 348 miners, brought from the same place, 25 from Wales, and others, natives of the county, were employed, but the quantity of silver raised has not been stated in the accounts. In the next reign, silver continued to be brought to the kings moneyers from these mines. (Weale's "Quar. Papers on Engineering," vol. v.) (No explosive used, of course.)

1303.—A gun, with this year engraved upon it, is said to be in the arsenal of Amberg.

1308.—The Spaniards used fire-arms.

1311.—Brescia attacked by Henry VII. with blunderbusses.

1312.—The Arabs had fire-arms at the siege of Baza.

1320.—BERTHOLD SCHWARZ IS SAID TO HAVE INVENTED GUNPOWDER (the year varies, with different authorities, between 1320, 1354, and 1380).

1326.—Martos attacked with fire-arms.

1331.—Fire-arms used before Alicante by the Moors.

1334.—The Margrave Este had muskets.

1338.—There is a report of powder and guns being used at the siege of Pui Guillaume. Guns are said to have been known in Prussia and Lithuania.

1340.—A powder-mill is said to have existed at Augsburg.

1340.—Guns used on the Salado, not far from Tanariffa (Tarifa ?).

1342.—Guns used at the siege of Algeziras (according to Juan Nuñez de Villasan).

1344.—(1357 or 1366, according to others) Petrarca describes the horrible effects of the newly-invented powder and guns.

1344.—Gunpowder was known in Spandau.

1346.—Guns used at the battle of Crécy.

1347.—Cannon used at the siege of Calais by Edward III. (according to Camden). (See Weale's "Quar. Papers on Engineering," vol. v.)

1356.—In the accounts of expenditures of the city of Nuremberg the first payments for powder and guns appear (Hoyer, on authority of Paul von Stetten, Augsburg, 1765).

1356.—The inhabitants of the city of Löwen bought 12 blunderbusses.

1360.—The City Hall of Lübeck burnt down in consequence of the negligence of powder-makers. (Hoyer, on authority of Herman Corner's chronicle of Lübeck.)

1360.—Senger, of Nuremberg, sold powder and guns.

1361.—In a sea-fight between the Danes and the Hanse, guns are used.

1364.—The city of Perugia ordered 500 muskets. (Hoyer, according to Pompeo Pellini's "Istoria die Perugia.")

1365.—The Margrave of Misnia had pieces of artillery. Einbeck defended by Duke Albert of Brunswick with a gun shooting lead. (Gramm, on authority of Rothe's chronicle of Thuringia.).

1370.—Duke Magnus, of Brunswick, used blunderbusses in his army. (Hoyer, according to Pütter's "Manual of the History of the German Empire," 1762.)

1372.—The inhabitants of Augsburg shot stones from metallic falconets upon Duke John, of Bavaria. (Hoyer, on authority of Paul von Stetten.)

1372.—Niklas van Rune, of Rypen, executed, because he took two small casks of sulphur and saltpetre to the enemy (according to a manuscript found by Gramm).

1372.—Guns used at the siege of Asti.

1373.—The citizens of Prague had a gunner.

1374.—The city council of Speyer had in its pay a master-gunner (according to Christof Lehmann).

1374.—The Paduans fired upon the Venetians' camp. (Hoyer, on authority of Chinnoza della guerra di Chioza, 1729.)

1377.—Richard II., of England, bought "two greater and lefs engines called cannons and 600 ftone fhot." In the same year, John Buch, the French admiral, had a ship with "three cannon, which caft forth darts."

1378.—John, of Aran, cast at Ulrichshof, in Augsburg, three large ordnance pieces, which threw balls of 127, 70, and 50 pounds to a distance of 1000 paces. How to load and fire these pieces he only taught the three counselors, Johann Venden, Johann Ilsyngen, and Johann Flinsbachen (authority of Gassarus).

1378.—Francis Carara used guns against the Venetians (according to Chinnoza).

1378.—The English had 400 cannon at the siege of St. Malo.

1379.—At the sea-fight near Chioza, guns used largely. (According to Andrea Gattaro's "Istoria Padovana," the Genoese had galleys provided with "bombarda," which they had previously taken from the Venetians.)

1381.—The citizens of Ghent used fire-arms against Bruges; also there was a bombard used which threw stones at the siege of Oudenarde, the report of which could be heard at night a distance of "ten hours' circuit" (about thirty to thirty-five English miles). Froissart says of the bombard used at the siege of Oudenarde, that it was fifty feet long, "and threw great, heavy stones of wonderful bigness. It might be heard five leagues by day and ten at night, making so great a noise as if all the devils in hell were abroad."

1381.—Augsburg furnished as a quota fire-arms and thirty harquebusiers (according to Zenk's chronicle of Augsburg).

1381.—The French threw "Greek fire" on the English at the siege of Barbourgh. (Weale's "Quar. Papers on Engineering," vol. v.)

1386.—The Paduans used small harquebusses against the Lord of Scala.

1393.—The Bishop of Mayence had guns.

1397.—POWDER-MINES USED AT THE SIEGE OF MERAT.

1400.—Powder known in Sweden. Henry V. forbade its export to England.

1402.—The citizens of Breslau had a gunner by the name of Niklas.

1408.—The people of Brunswick had a gun called the "Faule Metze."

1408.—Darts, or quarrels, shot from cannon. "The Earle of Kent was smote on the heade by a quarrel from one, and died." (Weale's "Quar. Papers on Engineering," vol. v.)

1412.—Gunpowder manufactured in England: this year its exportation was prohibited. A license granted to the ambassadors of the Earl of Alençon to carry home with them 400 lbs. of saltpetre and 100 lbs. of sulphur. These seem also to have been forbidden articles. Gunpowder, when first made, was not corned or granulated, but used in its mealed state, and was then called "serpentine powder." (Weale's "Quar. Papers on Engineering," vol. v., p. 34.)

1414.—The Brandenburgers had a gun called "Faule Grete."

1414.—At the siege of Arras, hand guns and leaden balls used against Charles VI.

1415.—Henry had cannon at the battle of Agincourt. The French within their lines had *saximova* (mangonels or bombards?) Elmham says that when the English army, commanded by the Duke of Gloucester, besieged Cherbourg in 1418, the besieged discharged *red-hot balls* of iron, to burn the huts in which the English soldiers were lodged; yet Polydore Virgil says that the French hardly knew the use of cannon by 1425. (Weale's "Quar. Papers on Engineering," vol. v.)

1419.—Henry V., of England, ordered 7000 stone cannon-balls made from quarries on Maidstone Heath.

1419.—Brass guns generally introduced.

1419.—Cannon-balls made of stone. Henry V., of England, commissioned John Louth, clerk of the ordnance, and John Reemnet, mason, in Maidstone, to make 7000 cannon-balls from quarries on Maidstone Heath. Twelve great carriages were to be provided for the land guns, and twenty pipes of powder made with "charcoal of willows." The use these balls were put to is given in an old chronicle: "Henry V. received a tauntyne meaffage frome the dolfin of Fraunce, and a tonne of tennes balles (in derifion). Hee anoone lette make the tennes balles for the dolfin to playe withalle. Hee playede att the tennes withe his harde gonneftones that were fhott into the towne, and whenne they beganne to playe, they withinne the towne fange well awaye, and fayde allas thatt evir fuche tennes balles were made, and curfede all thofe thatt the warre beganne, and the tyme thatt they evir were borne." The material the "gonnes" were made of seems to have varied. Caxton, in 1486, speaks of "a grete gonne of bras, and manie othere grete gonnes and ferpentynes." Balls of lead and iron were used, and "erthe balls," probably baked clay-balls. (Weale's "Quar. Papers on Engineering," vol. v.)

1423.—Muskets became more general in the Hussite wars.

1429.—The first shooting at a target with fire-arms on record was held at Nuremberg. (Memoirs of the City of Nuremberg.)

1430.—Target-shooting held at Augsburg. (History of the Imperial City of Augsburg.)

1430.—Hand-guns or hand-cannon were used at the siege of Lucca. They were soon after introduced into England. They are thus described by Billius, a noble Milanese: "The Milanese, besides darts, and what projected arrows, invented a new kind of weapon, also in their hands they held a sort of club, about 1½ cubits long; to this were affixed iron tubes which, being filled with sulphur and nitre, emitted iron balls. The blow, if it struck, was certain destruction: neither armor nor shield were sufficient protection, for often two or three deep, if fired upon, would be transfixed by a single ball. For two hundred years after the invention of gunpowder, all fire-arms were called cannon." (Weale's "Quar. Papers on Engineering," vol. v.)

1430.—Henry VI., of England, having failed in his attempts to procure gold and silver by the art philosophical, brought over, in 1430, Michael Gosselyn, George Harbryke, and Matthew Lameston, three famous miners, with thirty other miners in their company, from Bohemia and Hungary, to superintend and work the royal tin mines, and instruct the Cornwall men in their art. (Weale's "Quar. Papers on Engineering," vol. v.)

1431.—The Hussites took 150 cannon at Rosenberg from the Germans (according to Lenpant's "History of the War of the Hussites").

1435.—Harscher owned a stamp powder-mill at Nuremberg.

1439.—Archbishop Gunther, of Magdeburg, made wall nitre a royal prerogative.

1441.—Mines used at the siege of Belgrade.

1447.—The citizens of Erfurt, armed with muskets, ran to the walls when William of Saxony passed by. (Meekenii, Scriptor, 1730.)

1447.—Count Dünois set fire to the Audemer bridge with the same kind of rockets that had already been used at Chioza.

1461.—Some soldiers in England provided with hand-guns. These tubes were bound round at different distances of their length, being composed of two or more pieces thus held together. (Weale's "Quar. Papers on Engineering," vol. v.)

1475.—The use of powder mentioned in Russia.

1475.—Harquebuss invented. (Weale's "Quar. Papers on Engineering," vol. v., p. 39.)

1495.—Knut Posson, commandant of Wiborg, used powder-mines.

1500.—Pedro Navarro used mines at St. Georgio.

1503.—Also at the siege of Naples.

1520.—Gustavus I., of Sweden, ordered the earth of churchyards to be lixiviated for the purpose of extracting saltpetre. The peasants offered to furnish him saltpetre.

1523.—Mines used by the Turks at Rhodes.

1523.—At the siege of Milan, the mines sprung with bad success, so the besiegers returned to the old method of burning the supporting timbers.

1525.—Powder first grained.

1529.—The Turks used mines at the siege of Vienna.

1536.—Pollak built the first Silesian powder-mill.

1543.—Bombshells.—"The king, Henry VIII., minding," as Stowe has it, "his wars with France, made great preparations and provifions, as well of munitions and artillery. Among which at that time one Peter Callen, a gunfmith, conferring with Peter Bawd, devifed or caufed to be made certain mortar-pieces, being at the mouth from eleven to nine inches wide: for the ufe whereof, the faid Peter caufed to be made certain hollow fhot of caft yron, to be ftuffed with fyrework, whereof the bigger fort for the fame has fcrews of yron to receive a match to carry fyre for to break in fmall pieces the faid hollow fhot, whereof the fmalleft piece hitting a man would kill or fpoyl him. And after the king's return from Bullen, the faid Peter Bawd, by himfelf, did make certain ordnance of caft yron of divers fortes and formes, as fawconet, falcons, fakers, minions, and other pieces." (Weale's "Quar. Papers on Engineering," vol. v.)

1561.—There were 22 saltpetre manufactories in Sweden.

1561.—Queen Elizabeth, by the advice of her council, this year brought several Germans into England, who were experienced in mining. (Weale's "Quar. Papers on Engineering," vol. v.) (In 1564, the queen granted patents to two of these miners, Houghsetter and Thurland, to search for mines, etc., in eight counties. In 1566, a second patent was granted to William Humphreys and Christopher Shute (a German), to dig and work all mines, etc., in England, Wales, and Ireland, not included in Houghsetter's patent.)

1565.—The Turks used mines at Malta.

1574.—Lazarus Erker, of Prague, described the extraction of saltpetre.

1587.—In the instructions given to choose a harquebuss, "a Mylan peece," or barrel, is to be preferred, because "they bee of a toughe and perfect temper, lighte, fquare and bigge of breeche, and very ftrong where the powder doth lie, and where the violent force of the fire doth confiste, and notwithftanding thin at the end. Our Englifh peeces approach very neer unto them in goodneffe and beautie, their heavineffe only excepted, fo that they bee of purpofe and not one of thefe fale peeces with round barrels." (Weale's "Quar. Papers on Engineering," vol. v.)

1589.—Gun wheel lock (first used at the siege of Parma in 1521, when it was defended by the Marquis of Foix) introduced into England. It had previously been introduced into Germany in 1586. "It was," says Meyrick, "a contrivance for exciting sparks of fire by the friction of a furrowed wheel of steel at the bottom of the pan, which, with a quick revolution, grated against a piece of pyrites." (Weale's "Quar. Papers on Engineering," vol. v.)

1602.—The amount of saltpetre which could be extracted from a certain quantity of earth established in Sweden. Bianco speaks of powder-mills as existing.

1605.—Henry IV., of France, issued an ordinance with respect to the extraction and purification of saltpetre.

1607.—Fire-arms had now nearly wholly superseded the ancient catapult and bows. (Weale's "Quar. Papers on Engineering," vol. v.)

1613.—MARTIN WEIGEL, MINE SUPERINTENDENT OF FREIBERG, PROPOSED DRILLING AND BLASTING IN MINING.

1626.—General proclamation issued in England by Charles I. for "all our loving fub-

jects" . . . . . "to carefully and conſtantly keep and preſerve . . . . . all the urine of man and all the ſtale of beaſts during the whole year," to be used in the manufacture of saltpetre.

1627.—The practice of drilling and blasting said to have been carried from Hungary to Germany. (This date and the preceding 1613 are the prominent conflicting ones.)

1629.—A powder-mill, worked by horses, established at Breslau.

1630.—Patent granted in England to David Ramsay, for the manufacture of saltpetre.

1632.—Drilling and blasting introduced into the Harz Mountains.

1634.—The first expenditures for powder that are found in the weekly accounts of the Harz are of this date.

1640.—General Leslie surprised the English army with his *tin* artillery, covered with leather. They would bear two or three discharges. One Scott, a Scotchman, who had served under Gustavus Adolphus, was their inventor. (Weale's "Quar. Papers on Engineering," vol. v.)

1642.—The delivery of saltpetre made a duty in Sweden.

1643.—Drilling and blasting introduced into the mine Hohe Birke, in the district of Freiberg. At this date, in the Freiberg district, bore-holes were drilled generally to the depth of about 40 inches, and not less than 2 to 2½ inches in diameter. Each hole was charged with about 2 lbs. of powder, and the cost of boring a hole amounted to 16 g. Gr. 3 Pf. For firing a shot, 3 g. Gr. were paid. The wages for a shift of 8 hours were 4⅗ g. Gr. A Leipsic pound of powder cost at Freiberg 8 to 9 g. Gr.

1644.—During this year, 117 pounds of powder were used, and 57 shots (2 pounds of powder per shot) were fired in the mine Hohe Birke.

1669.—Mayon published his chemical analysis of powder.

1670.—Blasting introduced into England by German miners.

1673.—It is said that, prior to this date, one-hand drilling had been introduced.

1675.—As much as 300 pounds of powder were used at the mine Hohe Birke during the year.

1675.—99 cwt. 74½ lbs. of powder were used in the whole Freiberg district. (In the year 1843, the consumption amounted to 2439 cwt. 25 lbs.)

1682.—According to Calvör, the leather cartridges used in the Harz, formerly costing 4 Mgr. a piece, later 3 Mgr., were reduced to 2 Pf. in cost during the year.

1683.—Henning Huthmann, M.A., Rector of Ilefeld, proposed the first boring machine—a kind of large borer or stamp to be raised by a rope drawn by two men, and then dropped. (Calvör.) (The weight of authority seems to be that this was a kind of large shaft-borer, rather than a rock-drill.)

1685.—Tamping with clay was at this date known in Saxony (according to notes on the account-sheets of the year 1715).

1686.—Vauban and Migrini made experiments in regard to military mining at Douay and Tournay.

1686.—Brass-loading needle introduced (according to Calvör).

1687.—Charles Zumbe introduced into the Harz, tamping with clay and reeds filled with powder for firing.

1688.—The Obergeschworene Singer, of Clausthal, introduced small firing tubes of hard wood. (Calvör.)

1689.—Hans Luft, a bookbinder of Clausthal, introduced pasteboard cartridges in place of the old leather ones. (Calvör.)

1693.—19 cwt. of powder shipped weekly to Clausthal during the year. (Calvör.)

1693.—An order issued in the Harz that blasts should only be fired at fixed times.

1696.—Drill-holes reduced to $1\frac{1}{2}$ inches in diameter, also bored only to the depth of 14 to 18 inches where required, instead of the old deep holes.

1717.—Fritsch proposed to save powder and to break the rock by wedges driven into the bore-holes.

1720.—One-hand drilling introduced in the Harz Mountains. (Up to this date—*i. e.*, about one hundred years from the introduction of drilling—either two or three hammers had been used to a drill in all work.) In this year, Stahl made researches on powder.

1721.—Bartels, of Tellersfeld, is said to have invented a machine for drilling or boring (said to be for shafts).

1724.—Drilling and blasting introduced into Sweden by German miners.

1725.—At this date, the effect of simultaneously firing several adjoining shots was already known at Bohemian and Saxon Zinnwald.

1725.—Belidor made his experiments with mines at La Fére, and established a new theory of mines in warfare, overturning Vauban's doctrine.

1747.—An ordinance published by the chief mine office at Freiberg, "that hammer and gad work be discontinued as far as possible, and drilling and blasting adopted throughout instead."

1749.—Silberschlag blasted ice in the Elbe at Klosterbergen.

1749.—Hungarian miners first introduced the chisel-bit drill into the Harz. (For a period of one hundred and thirty-six years from Weigel's day to this date, all drilling had been done by means of crown and cone drills.) (See Figs. 17 (*a*) and 17 (*b*), p. 102.)

1753.—An "air-engine" used at Schemnitz by Holl for raising water.

1755.—An extraordinary reward fixed in France for the best method of manufacture of saltpetre.

1759.—Drilling with a chisel-bit introduced into Saxony.

1760.—Thunberg introduced into Sweden tamping with wedges.

1767.—According to reliable reports, simultaneously firing was in vogue at this date in Saxony.

1788.—Lavoisier enunciated his theory of the combustion of powder.

1788.—Picric acid discovered.

1790.—Wentzel and Dr. Baader tried firing with a hollow space, and used gypsum as a tamping. In this year, Baader promulgated his theory of blasting.

1791.—Le Plat used sand as a tamping.

1792.—Seiffert, a mine boss, proposed to use a kind of wooden plug in blasting.

1792.—Baader proposed making the holes narrower at the bottom, and using the shoulder-borer.

1795.—Humboldt proposed making the holes wider at the bottom (of a conical shape).

1795.—Seiffert's wooden blasting plugs introduced at Freiberg by ordinance.

1796.—The manufacture of a fulminating powder commenced, consisting of carbon, sulphur, and chlorate of potash, suggested by Berthollet (soon discontinued on account of an explosion).

1802.—Schroll recommended leaving a hollow space below the powder.

1802.—Schroll introduced plugs, which afterward were known by the name of Salzburg plugs.

1803.—A machine said to work "quicker than a miner," made by Gainschnigg, at Salzburg.

1811.—Spangenberg, a mine boss, at Suhl, used wooden tamping rods, also wooden needles and soft clay for tamping.

1816.—Varnhagen mixed powder with sawdust and foreign substances, to produce greater effect.

1822.—Serullas proposed using, in subaqueous blasting, instead of powder, an explosive which would ignite on coming in contact with water.

1823.—Harris succeeded in firing a blast by the electric spark. (Franklin is said to have previously tried this.)

1823.—Sir William Congreve invented his time-fuse.

1828.—Russian army officers said to have been the first who fired mines by electricity.

1829.—Needles used in the district of Ehrenfriedersdorf made of a composition of lead and tin (1 : 4).

1829.—Moses Shaw, of New York, FIRED SEVERAL CHARGES OF GUNPOWDER SIMULTANEOUSLY, by passing an electric spark through a priming composed of the fulminate of silver. He took out a patent for the process June 3d, 1830. (See "Journal of the Franklin Institute," vol. vi., p. 218, Oct., 1830; and p. 40 of this work.)

1831.—Bickford invented his safety-fuse.

1832.—Braconnet discovered that by dissolving starch in nitric acid, and adding water, a white explosive substance was precipitated, to which the name xyloidine was given.

1834.—Oberlieutenant Peschel proposed ignition by means of percussion.

1835.—Piobert made experiments to render gunpowder safer by enveloping the grains in some inert finely divided material. Same idea was tried by Fadéiff, 1841–'44; by Ryley (who used sand), 1855; and by Gale (powdered glass), 1855. ("Chemical News," London, No. 344; "Engineering," vol. i., 65; "Mechanics' Magazine," July, 1865.)

1836.—An order issued at Freiberg directing care to be used in charging and tamping.

1836.—Piobert published his experiments as to the rapidity of combustion of powder.

1838.—Dr. E. Davy first discovered a "sensitive" powder (fulminate of copper).

1838.—Prideaux used oxyhydrogen gas for deepening bore-holes, and with it burnt a hole at a rate of ½ of an inch per minute.

1838.—Pelouze showed the action of nitric acid on ligneous fibre.

1839.—Pasley used iron cones for tamping in England. Also, in this year, Pasley exploded gunpowder under water by the electric current. ("Mechanics' Magazine," London, 1839, vol. xxx., p. 480.)

1839.—Whalebone needles introduced into the Freiberg mines.

1839.—Triger tried firing shots in compressed air (three atmospheres).

1840.—Bore-holes made with rotary drills at Lankowitz.

1841.—Von Würth invented his new method of tamping.

1842.—Captain Kurtz, of Clausthal, introduced a new firing arrangement (wooden rammers and needles, with the upper part of iron).

1843.—Charges of some 18,000 pounds of powder fired at Dover by electricity.

1843.—Thomson enclosed the electric battery in an air-tight chest with chloride of lime to avoid moisture.

1843.—Schmiedhuber tried how electric firing could be applied to small charges with economy.

1844.—Caligny published his idea of applying the hydraulic ram to compressing air.

1844.—Brunton proposed using compressed air for working drill-hammers; the air after use to improve ventilation.

1844.—Combes mentions the use of a rotary borer in rock.

1844.—Bickford's fuse tested at Freiberg.

1844.—Hollow needles used at Freiberg to avoid compressing the air.

1844.—Courberaise enlarged the bore-hole in limestone by the use of muriatic acid (making a bottle-shaped cavity).

1845.—Cast-steel drills tested at Freiberg.

1846.—Schoenbein exhibited a sample of gun-cotton at the British Association, September 1st.

1846.—Lewis Thompson discovered nitro-sugar, and published a description of it December 8th.

1847.—Sobrero discovered nitro-glycerine.

1849.—J. J. Couch, of Philadelphia, patented, March 29th, the first percussion rock-drill ever made. In it the drill was not fastened to the piston-head, but thrown, like a lance, at each stroke; and, in this year, a caveat was also filed by Fowle for his direct-action drill, subsequently patented (see year 1851 below).

1849.—Mauss perfected his plan for a rock-cutting machine, to be used at Mont Cenis. (His first proposal was in 1845, and the plan was finally abandoned in 1850.)

1851.—J. W. Fowle, of Philadelphia, patented, March 11th, the first direct-action percussion rock-drill invented; he filed caveat at the Patent Office in 1849 (see above).

1851.—Cavé, at Paris, invented and patented (October 15th) his percussion power-drill.

1853.—Krammer used rotary drills (in the construction of the Karst Railroad) for boring limestone.

1853.—Piatti proposed using compressed air in the construction of the Mont Cenis Tunnel.

1854.—First trials made with Bartlett's rock-drill.

1854.—Gurlt published his theory of blasting.

1854.—Sommeiller, Grandis, and Grattoni's experiments with compressed air were made for the Mont Cenis Tunnel.

1854.—In 1854–'55, Schumann invented his percussion power-drill at Freiberg. It was introduced into the Rothschönberg Tunnel in 1857.

1855.—Colladon, of Geneva, proposed the plan of compressing air finally adopted at Mont Cenis.

1856.—From 1856 to 1861, Herman Haupt, during his contract at Hoosac Tunnel, experimented with power-drills of the hollow-piston or Couch type. In these experiments, he was assisted by Stuart Gwynn. It is claimed that Gwynn's first drawings for a drill were made in 1851, and a model in 1852.

1857.—Schumann applied his boring-machine in the Freiberg mines.

1857.—Sommeiller invented the rock-drill for Mont Cenis.

1857.—Lieutenant-Colonel Baron von Ebner introduced into use a frictional electric-machine for blasting.

1857.—Major Rodman's experiments with explosives were made.

1857.—Trials made with Schwarzkopf's rock-drill.

1857.—The official commission decides in favor of the application of Sommeiller's rock-drill for use at the Mont Cenis Tunnel.

1861.—On the first of the year, Sommeiller's perfected drill commenced to work in the Mont Cenis Tunnel.

1861.—P. v. Rittinger recommended a cylindrical rotary boring-machine.

1861.—Harsen's rock-drill patented. (This drill was tried in the Hoosac central shaft in 1865.)

1861.—Lisbet applied his boring-machine in soft rock (coal, soft limestone, etc.)

1862.—Use of gun-cotton revived in England.

1862.—Bornhardt's air-tight electric firing-machine successfully tested.

1862.—Captain Edward Ržiha invented an odorless fuse.

1863.—NOBEL FIRST APPLIED NITRO-GLYCERINE AS A BLASTING AGENT.

1863.—Low's rock-drill invented.

1863.—Sach's rock-drill invented.

1865.—Haupt's rock-drill patented.

1865.—Costelay and Dessignoles discovered an economical method of manufacturing picric acid.

1865.—Gun-cotton tried at Hoosac Tunnel by Thomas Doane, Chief Engineer.

1865.—Nobel's American patent for nitro-glycerine, applied as a blasting agent, taken out.

1866.—Newmeyer's powder invented.

1866.—Lithofracteur first manufactured by Engels (later Krebs & Co.), near Cologne.

1866.—Nitro-glycerine tried with great success at Hoosac Tunnel by Tal. P. Shaffner, under the direction of Thomas Doane, Chief Engineer.

1866.—Tal. P. Shaffner took out a patent for mixing "nitroleum" (nitro-glycerine) with sand in a bore-hole.

1866.—(June.)—Brooks, Gates & Burleigh machine tried and pronounced a failure at the Hoosac Tunnel.

1866.—(November.)—The Burleigh drill tried and proved to be a success at the Hoosac Tunnel.

1866.—(June.)—The Robinson and Wood drill tried successfully at Ann Arbor (see p. 166 of this work).

1867.—Glyxoline invented by Abel, of England.

1867.—NOBEL INVENTED DYNAMITE.

1867.—(November.)—The Robinson & Wood drill patented.

1868.—During the winter of 1867–'68, W. P. Granger upset a sleigh full of frozen nitro-glycerine in crossing Hoosac Mountain, and unintentionally demonstrated that it was not readily exploded by shock when frozen.

1868.—Dynamite patented in America by Nobel.

1868.—Dubois-François rock-drill invented.

1869.—Julius Smith applied Baron von Ebner's frictional electric-machine in America.

1870.—Dualin invented by Carl Dittmar, a Prussian officer.

1871.—Ingersoll rock-drill patented.

1872.—MacKean rock-drill patented.

1873.—Wood rock-drill patented.

1873.—Judson's giant-powder (dynamite) No. 2 patented.

1873.—Beach patented rend-rock powder.

1873.—Ferroux rock-drill invented.

1873.—Darlington rock-drill invented.

1874.—Mowbray's mica-powder patented.

1876.—Judson powder (XX) patented.

1876.—Hell-Gate blown up by General Newton.

1882.—Nobel's gum dynamite generally accepted in Europe as preferable to No. 1 dynamite.

CHAPTER III.

MODERN EXPLOSIVE COMPOUNDS.*

HAVING now reviewed the general history of explosive compounds, it remains to especially notice those in general use at the present day, and in this connection it is only proposed to give a very general summary, for a tunnelman is chiefly interested as to the chemistry of explosives, in considering what effect the gases set free by combustion may have on ventilation.

The practical efficacy of the different compounds in blasting, and the results obtained by their use in various localities, will be considered under the head of "Blasting." André has defined an explosive compound to be "a mixture of substances capable of being suddenly transformed into gases by the application of heat." Hill defines an explosive reaction to be "a chemical action causing the sudden or extremely rapid formation of a very great volume of highly expanded gas."

Hence an explosion is a sudden evolution of gases; and as these gases occupy a much larger volume than the original substances from which they were evolved, pressure will be produced upon the body in which they are retained. It is obvious that the degree of pressure which represents the strength of the explosive will vary as the volume of the gases evolved, and thus we have a means of measuring and comparing the strength of the various compounds, and the volume of the gas, again, will depend upon the pressure exerted and upon the temperature. The effect of an explosive, however, does not depend wholly upon the volume of gases; an equally important consideration is that of the time required for the change to take place. This latter consideration can be most strikingly exemplified by the fact that the same explosive will give vastly different effects, according to the manner in which it may be fired—*i. e.*, whether the evolution of gases takes place gradually from one grain or molecule of the substance to another, as in firing by a fuse, or practically simultaneously from all the grains or molecules through detonation.† Further, the temperature to which the gases evolved are raised, is an important consideration in discussing either an explosion proper or a detonation.

GUNPOWDER.

Gunpowder is a mixture of saltpetre, sulphur, and charcoal.

A good powder must possess the following properties:

Its grains must be firm, hard, angular, and of equal size.

The powder must be dry, free from dust, absorb but little moisture from the air, and should not show a mixture of variously colored particles. Powder also when ignited on writing-paper should flash without burning the paper.

According to the kind of charcoal used (whether "black" or "red"), powder may have a blue or deep black or again a faintly brownish color.

* The author is indebted to Mr. E. P. North, M. Am. Soc. C. E., for a careful review and criticism of this chapter, both in the original MSS. and in the proof-sheets; also to Prof. B. W. Frazier for a criticism of the proof-sheets, and for various corrections and notes relating particularly to the chemical constitution of explosive compounds; also to Dr. Robert Grimshaw for valuable assistance in the collection of data.

† See p. 96.

The following analyses of various powders are cited by Ržiha.*

TABLE 4.

BRAND.	CONSTITUENTS, IN 100 PARTS.		
	Saltpetre.	Charcoal.	Sulphur.
Austrian Blasting Powder	60·194	21·359	18·447
French Round Grain Blasting Powder	62·00	18·00	20·00
Harz Blasting Powder	62·11	21·28	16·41
Russian Blasting Powder	66·70	16·70	16·60
Westphalian Blasting Powder	68·34	15·83	15·83
Italian Military Blasting Powder	70·00	12·00	18·00
Freiberg Double Powder	73·60	13·00	13·40
Austrian Musket Powder	75·00	13·00	12·00
Russian Sporting Powder	80·00	12·00	8·00

Also the following by Schoen: †

TABLE 5.

	ACCORDING TO LENK.	ACCORDING TO KÁROLYI.	
	Würtemberg.	Austrian.	
	Musket Powder.	Cannon Powder.	Musket Powder.
Saltpetre	74·70	73·78	77·15
Sulphur	12·45	12·80	8·63
Carbon	9·05	10·88	11·78
Hydrogen	0·41	0·38	0·42
Oxygen	2·78	1·82	1·78
Ashes	....	0·31	0·28
Hygroscopic Water	0·60	....	....
	99·99	99·97	100·05

Seven analyses‡ of different kinds of blasting powder used for mining purposes gave the following average:

Saltpetre	63·33
Sulphur	15·89
Charcoal	19·39
Hygroscopic Water	1·36
	99·97

American blasting powder is of several kinds and of various grades, according to the work it is intended to perform, whether tunneling, boulder, or railroad work, or for use in mining anthracite or bituminous coal.

That used in rock work, tunnels, or iron mines is usually composed of saltpetre 72, charcoal 17, sulphur 11 per cent. For coal mining the proportions are usually about nitre 70, charcoal 18, and sulphur 12.

It is said that in the manufacture of gunpowder, the difficulty of obtaining a uniform product results from the varying nature of the constituents used. The quality of the charcoal

* "Lehrbuch der Gesamm. Tun.," i., p. 86. † "Der Tunnelbau," p. 61. ‡ Ibid., p. 62.

especially is very apt to vary in different batches. A series of valuable experiments on the manufacture of gunpowder without water were made by a Russian commission in 1871. (See, for a full description, Van Nostrand's Magazine, vol. 18, p. 437.)

Ignition and Explosion of Powder.

Powder may be ignited by impact, but with great difficulty. Ignition is most readily effected by a blow of iron upon iron, and in successive order of iron upon brass; brass upon iron; lead upon wood; and least readily from a blow of copper upon copper; copper upon bronze or wood.

According to Violette, granulated powder is exploded by rapid heating to a temperature of from 518° to 608° F. (270° to 320° C.); powder-dust, sooner. By slower heating, the sulphur ignites first, at a temperature of 842° F. (450° C.)

Powder is well ignited only by,

(*a*) Application of any substance heated to redness. Flame alone will not so readily ignite powder. Where safety-fuse is used, the powder-train in it is generally ignited from the burning of the linen or cotton envelope.

(*b*) Tinder.

(*c*) A burning brand.

(*d*) Thin steel or platinum wire heated red-hot by the galvanic current.

(*e*) Exploders of fulminating powder fired by the electric spark passing through some sensitive powder placed adjoining it in a cap. These are the exploders for gunpowder described* on p. 111.

Again, according to experiments made by Munks, Bianchi, and Heeren, in a partial vacuum, powder did not explode when touched by glowing bodies, or on passing the electric spark, etc.; raised to a red heat in vacuo, it burned slowly; again, in a chamber filled with nitrogen, it exploded as in the open air.

Different experiments, made with the view of determining the amount and proportion of the evolved gases on the combustion of gunpowder, have given widely different results. Thus 1 cubic centimetre (0·06 cub. inch) of gunpowder gave from 232 up to 450 cubic centimetres of gas, the average being 318 cubic centimetres (19·4 cub. in.), at a temperature of 0° C. (32° F.), and a barometrical pressure of 760 mm. (29·92, say 30 inches).

Gay-Lussac, as well as Chevreul, found that after the explosion the evolved gases consisted chiefly of nitrogen and carbonic acid, combined with some carbonic oxide and a little carburetted hydrogen.

After the most careful investigations, the following products of combustion were obtained by Károlyi from burning powder, under circumstances similar to when it is fired in a cannon.

TABLE 6.

FROM ONE GRAMME OF	CANNON POWDER.	MUSKET POWDER.
Residue in grammes	0·692	0·651
Gases in grammes	0·307	0·348
Total { Grammes	0·999	0·999
Total { Cubic centimetres of gas	206·9	226·6
Total { Cubic inches of gas	13·6	13·8

* Shaw, of New York, in 1830, was the first to explode charges simultaneously by means of electricity. An interesting note by Prof. M. S. Gätzschmann, on the adoption of electric firing in the Freiberg mines, will be found in Dingler's "Polytechnisches Journal," vol. cxxviii. (1853), p. 454. See also an article on the same subject by Prof. Carl Kuhn, of Munich, in the same Journal, vol. cxlv. (1857), pp. 186 *et seq.* Also ante p. 40.

(As to the proportion of residue left from the combustion of gunpowder, see p. 76).

Now, as we have said before, to a tunnel engineer, the chemical constituents of the residue left, or the original combinations of sulphur, oxygen, carbon with potash, etc., in the powder itself, are of little moment; but the chemical constituents of the mixture of gases resulting from combustion are of decided interest. These, according to Károlyi, are as follows:

TABLE 7.

	IN PER CENTS OF VOLUME.	
Nitrogen	37·58	35·33
Carbonic Acid	42·74	48·90
Carbonic Oxide	10·19	5·18
Hydrogen	5·93	6·90
Sulphuretted Hydrogen	0·86	0·67
Fire-damp	2·70	3·02

Thus of the gases affecting ventilation, we have chiefly carbonic acid, nitrogen, and carbonic oxide.

These analyses are, of course, merely general, for both the residue and gases evolved will differ according to the mixture of ingredients in the manufacture of different brands of powder.

Now, the working strength of gunpowder may be estimated by the following considerations:

According to Bunsen, the temperature of the ignited gases of powder amounts, in the open air to 5419° F. (2993° C.), in a closed chamber to 6044° F. (3340° C.), say 3300° C., as we are considering the gases when in a closed chamber or bore-hole. Bunsen decided that the pressure or tension evolved on explosion amounted to more than 4300 atmospheres and to a theoretical effect of 67,410 metre-kilogrammes (487,576 foot-pounds). According to others, the pressure may increase to 10,000 atmospheres; and Rumford even obtained, under certain circumstances, 29,178 to 54,740 atmospheres. Rodman's measurements of pressure gave results differing greatly from each other according to the charges. In a cannon, the greatest pressure observed by him amounted to 6700 atmospheres; in a bombshell of which the exterior diameter was 31·4 c. (12·36 inches) and the interior diameter 10·4 c. (4·09 inches), which, therefore, had a thickness of shell of 10·5 c. (4·13 inches), it amounted to over 12,300 atmospheres.

The following table is quoted by Ržiha * from Gätzschmann, as giving results obtained by different experimenters:

	In Atmospheres.
Robin	1,000
Hutton	1,700 to 2,800
Meyer	3,809 " 4,000
Briançon	4,000
Prechtl	4,400
Karmarsch and Heeren	5,000
Gurlt	3,930 " 8,640
Piobert	7,500
Bernouilli	10,000
Rumford	29,178 " 54,740

* Lehrbuch der Gesammten Tunnelbaukunst, p. 87.

For blasting, we may perhaps assume 4300 atmospheres and a theoretical effect of 42,000 metre-kilogrammes (303,786 foot-pounds), which result also agrees very well with the ingenious theoretical computation of the effect of powder in blasting, made by Stadler. (See "Oesterr. Ingenieur-Vereins Zeitschrift," 1866; Schoen, "Der Tunnelbau," 1874, p. 64.)

Now, again, the working strength of gunpowder may be said further to be determined by,

(1) The ratio existing between the volume of the residue and the volume of the evolved gases.

(2) The heat evolved at combustion and the specific heat of gases evolved; for upon these depends again the expansion of gas during the explosion, therefore their cooling by the surrounding rock is also of some influence.

(3) The air enclosed between the grains of powder, and the effect of its moisture on the heat evolved by combustion.

(α) As inducing imperfect combustion. (β) As affecting the expansion of the hot gases.

(4) The expansion of the solid residue after combustion.

(5) The rapidity of ignition of the powder. This may be modified,*

(α) By varying the size and form of the grains or individual mass. (β) By varying the density or compactness of the powder. (γ) By variations in the finish or nature of the surface of the grains or mass.

(6) The question whether the quality of the powder has not suffered during storage,

(α) In consequence of a long interval having elapsed between manufacture and use, which interval, it is said, acts in an increasing ratio. (β) In consequence of comminution producing a diminution of the grains in size, and an increase of powder-dust. (γ) In consequence of spontaneous decomposition.

Some of these considerations will also apply to other explosives in use; we will now briefly touch on the chief ones.

Other Explosive Compounds.

Haloxyline,† according to Cerny, is composed of charcoal, saltpetre, ferrocyanide of potassium, and some cyanide of potassium. It is produced in grains like common powder. Haloxyline ignited in the open air burns slowly with a violet flame and grayish white smoke, without exploding. It is not ignited by pressure, friction, or impact of even powerful blows of iron upon iron. Ignition is only effected by spark or flame, and heating above 480° F. (250° C.). Therefore, as compared with common powder, haloxyline would seem to offer greater safety in handling. Haloxyline, rammed firmly in a bore-hole, is said to exert a blasting force amounting to twice that of an equal weight of common powder. When complete ignition is effected, there is little residue; should the rock be blackened, it is proof of imperfect explosion. No smoke results from combustion, and the gaseous products are neither unpleasant nor injurious. In blasting with haloxyline, the rock is slowly lifted and rent, the explosion is not violent. As the fragments are not scattered, as with a quicker

* "Paper on Modern History of Gunpowder," from the Journal of the Society of Arts, vol. 21, p. 202.
† Schoen, "Der Tunnelbau," p. 64.

explosive, it is very suitable for blasting at places where attention is to be paid to surrounding objects, buildings, etc. The report is dull, and not so loud as that with equal amounts of common powder. It has been observed particularly, that even during continued blasting in a confined space, the inhaling of the gases evolved did not prove disagreeable or injurious to the workmen. After firing, the men may go directly to the working face, without waiting, as is often necessary with other explosives, for the atmosphere to clear a little. (The above facts concerning haloxyline are given wholly on the authority of Schoen. It has not been used largely in this country, but it seems to have attained considerable favor in Austria. Haloxyline has been described at some length, as it is well spoken of in Schoen's work.) There have been in the last twenty years numberless compounds tried; in fact, there can be as many explosives manufactured as there can be proportions devised in which explosive substances can be mixed. Among them are mixtures of the chlorate of potassa with resin or with powdered nutgalls (Horseley's powder; this has subsequently been used with 25 per cent nitro-glycerine), and with many other substances. A patent was actually taken out for a "compound for blasting purposes of 40 per cent charcoal and 60 per cent nitrate of soda." Even the old and well-known mixtures of chlorate of potash with the ferro- and ferri-cyanides of potassium and sugar, which for many years have been described in the chemical text-books as *white gunpowder* and *German* gunpowder, have been heralded as new blasting compounds. Reveley's white gunpowder was composed of

Chlorate of Potash	48 parts.
Yellow Prussiate of Potash	29 "
Finest Loaf-sugar	23 "
	100 parts.

The practical objection to these mixtures, that they are too dangerous to handle, being of a detonating character, is met by their advocates with the answer that they need not be mixed until required for use. Now, this would require the ordinary miner to be both chemist and blaster at once. This is analogous to Capt. Ryley's proposition * to render gunpowder safe by enveloping the grains in bone-dust, which was proposed by him about 1855; also Gale's † (1865) more recent proposition to mix it with ground glass for storage and transport, and then sift it when required for use. It is hardly necessary to enlarge on the great difficulty of having to prepare an explosive mixture just when it is required for use. Besides, the great danger incurred in the use of explosives is in the very charging of the mine or hole, and here it is that the large proportion of accidents occur.

One of the latest forms in which this principle has been revived is in a new explosive compound called "Rackarock," sold by the Rendrock Powder Company of New York. This explosive is formed by the union of two substances, one solid and the other fluid, it being claimed that either substance is absolutely inexplosive until combined with the other. The comminuted solid is made up into porous cloth cartridges. When it is desired to use these, they are placed in a sieve and immersed in a vessel containing the vitalizing liquid, until they show in a spring balance to which the sieve is suspended that they have absorbed the requisite weight of fluid. The proportion of oil absorbed is shown by tables furnished by

* "Engineering," vol. i., p. 65 (1866). Note is here made of Capt. Ryley's experiments, and of a proposal (1848) to render gunpowder non-explosive by mixing it with sand.

† "Mechanics' Magazine," London, July, 1865, and "Journal of Royal United Service Institution," Whitehall Yard, London, May, 1866, p. 165. (See also "Chemical News," No. 344, London.)

the makers. It is claimed by the makers that the fluid used contains no nitro-glycerine in any shape, but beyond this we have no information as to the nature of the ingredients employed. The cartridges can, it is said, be used either in wet or dry holes, and are fired by an exploder as with dynamite.

The author saw two large blasts made with Rackarock at a limestone quarry, by Mr. Rand, in the presence of a number of members of the American Institute of Mining Engineers, during the session of the Institute in October, 1881; these blasts were considered as giving very favorable results. No absolute conclusions, however, could be drawn in the limited time and number of blasts possible under the circumstances; nor were any underground trials made to test whether or not the gases of combustion would prove noxious in a confined space.

Reynolds' Explosive:—Prof. Emerson Reynolds claims to have discovered a new and valuable explosive compound composed of a mixture of 75 per cent of chlorate of potash with 25 per cent of a substance he terms "sulphurea," which, it is said, can be prepared in large quantities from one of the waste products in gas manufacture. The new explosive is described as being white in color, and easily prepared. It ignites at a rather lower temperature than gunpowder, leaving only 45 per cent of solid residue.

Again, Capt. Schultze, a Prussian artillery officer, prepared an explosive he called gun-sawdust by digesting sawdust in a mixture of sulphuric and nitric acid. This gives a feebly explosive material, which is further strengthened by impregnation with nitrates, by which it acquires great explosive power, its properties being somewhat similar to gun-cotton. Subsequently, Capt. Schultze tried mixing this gun-sawdust with 17 to 20 per cent nitro-glycerine. (This explosive must not be confounded with Dittmar's dualin, in which sawdust acts as an absorbent for nitro-glycerine. See p. 87.) As, however, in Schultze's gun-sawdust, to be within the limits of safety, the nitrates must not be added until the powder is required for use, and even then refined manipulation is required, this explosive did not come into general use. In this connection we may note xyloidine, prepared by azotizing starch; nitro-mannite, from azotizing sugar of manna, and nitro-cane-sugar, made by azotizing cane-sugar, etc. In fact, a very large number of these compounds can be prepared, and have been, by different experimenters. They, however, have no practical utility, so far, as explosive agents. NEUMEYER'S POWDER* is said to be composed of the same ingredients as ordinary gunpowder, but mixed in different proportions. It was introduced in 1866 into England, but did not come into general use. Another mixture of the ordinary components of gunpowder, recently brought into use by Curtis & Harvey, in England, is well spoken of by André,† as being so rapid of ignition as to be capable of detonation (see p. 97).

HOCHSTÄDTER'S GUN-PAPER (repatented in England by Reichen in 1866) is made by soaking unsized paper in a thin paste of chlorate of potash, charcoal, and sulphide of antimony.

GUN-COTTON.

Gun-cotton, or pyroxyline, discovered by Schönbein in 1846, is a so-called nitro-compound, prepared by exposing dry cotton for a sufficiently long time to the action of a mixture of the strongest nitric acid with sulphuric acid, and then by thoroughly washing the gun-cotton thus prepared, to remove the excess of acid. The reaction consists in the substitution of nitrogen and oxygen in feeble combination for part of the hydrogen in the cotton or cellulose, and is therefore similar to the one by which nitro-glycerine is produced.

* Paper on Explosives, by Perry Nursey, before Society of Engineers, London, 1869.
† André on Coal Mining, pp. 194 and 207.

The formula $C_{24}H_{18}O_{18}2NO_5$ was given by Pelouze. Abel found for Lenk's gun-cotton $C_{12}H_7(NO_4)_3O_{10}$; the formula given in Hill "On Explosives," for gun-cotton, is $C_6H_7(NO_2)_3O_5$ or $C_6H_7N_3O_{11}$*; this is the trinitro-cellulose. Gun-cotton is insoluble in and unaffected by water. Gun-cotton, in a measure, is an explosive both of the first and of the second order (see p. 97). Its best effect, however, is given when detonated by an exploder.

Imperfectly converted or badly washed gun-cotton is liable to spontaneous decomposition, which may result in explosions if the conditions are favorable. The pulped and compressed form is free from such danger, for since it can be fired wet, there is no need of ever drying it, so that it may be kept and used saturated with water. For firing it wet, a primer is needed, made of a cake of the dry, with a fulminating fuse attached. This primer must be enclosed in a water-proof bag or box. It is said that† wet compressed gun-cotton is in reality one of the safest of explosives, for it is not liable to be fired by a spark or a flame, nor affected by blows, friction, or other rough handling. Gun-cotton for a long time after its discovery was not put to practical use, as various attempts to apply it were checked by accidents which seemingly could only be referred to spontaneous decomposition. The trouble lay in the imperfect purification in manufacture. By Abel's method, however, a very perfect washing is obtained, and, in addition, the material is prepared in a form convenient for use, it being first reduced to fine pulp and then compressed into convenient shapes.‡

On being exploded, gun-cotton burns to water and gas without leaving appreciable residue, dust, smoke, or blackening. The gases are inflammable, burning with a bluish flame.

As to the gases evolved by combustion, it is said that from one gramme (0·035 oz. avoir.) of gun-cotton there are evolved at combustion in vacuo, in round numbers, 588 cub. ctms. (35·87 cub. inches) of gas measured, according to Hecker and Schmidt, at a temperature of 32° F, (0° C.) and a barometrical height of 760 mm. (29·922 inches). Károlyi found at a temperature of 32° F. (0° C.) and a barometrical height of one metre (3·281 ft.) (hence under high pressure), 574 cub. ctms. (35·014 cub. inches) of gas.

Blondeau obtained from one gramme (0·035 oz. avoir.) of gun-cotton saturated with ammonia, 955 cub. ctms. (58·25 cub. inches) of gas, and other statements go as far up as 1200 cub. ctms. (73·2 cub. inches).

The temperature of combustion of the gases amounts, in round numbers, to 8132° F. (4500° C.).

The chemical constituents of gun-cotton differ greatly according to its preparation, and vary with respect to

Carbon,	between	24·59	per	cent	and	26·40	per	cent.
Hydrogen,	"	2·43	"	"	"	4·10	"	"
Nitrogen,	"	9·30	"	"	"	14·34	"	"
Oxygen,	"	58·14	"	"	"	60·90	"	".

Ash residue is from 0·63 to 1·14 per cent. Water, on an average, 2 per cent; maximum, 8 per cent.

The fumes from gun-cotton differ from those from nitro-glycerine, as gun-cotton lacks 24·24 parts of oxygen in 100. Hence we have as the result of explosion (Károlyi):

* (Abel's and Hill's formulæ are the same, except that Abel uses the *old*, and Hill the *new*, system of atomic weights.)

† Hill, Explosives, p. 46.

‡ See paper by Abel, published in Van Nostrand's Magazine, vol. 18, p. 40, from "The English Mechanic and World of Science," describing the advantages of using wet gun-cotton.

TABLE 8.*

	IN VACUO.	UNDER HIGH PRESSURE.
Carbonic Oxide	28.55	28.95
Carbonic Acid	19.11	20.82
Fire-damp	11.17	7.24
Nitrous Oxide	8.83	....
Nitrogen	8.56	12.67
Aqueous Vapors	21.93	25.34
Hydrogen	....	3.16
Carbon in excess	1.85	1.82
	100.00	100.00

Assuming 4500° C. (8132 F.) as the temperature of gases of combustion of gun-cotton, the theoretical maximum pressure in atmospheres 15,300, and the theoretical maximum power in kilogrammetres equals 200,000. (Trauzl.) In soft rock, gun-cotton is said to exhibit twice, in hard rock five to six times the blasting effect of gunpowder.† Hill gives its explosive force as varying from four to six times that of gunpowder.‡

For the system of manufacture of gun-cotton at the United States Torpedo Station at Newport, R. I., see Hill on Explosives, p. 42, where a description of Abel's process is given. Also for an outline of Lenk's process, see the "London Chemical News," No. 234, Abel on the "Chemical History and Application of Gun-cotton."

* Sarrau and Vielle made researches with a view to fixing the use of gun-cotton in mines. (See paper from English Mechanic, Van Nostrand's Ecl. Mag., xxiii., p. 249.) In their first communication to the French Academy, they studied the products formed and the heat given off, by the explosion in a closed vessel,

1. Of pure gun-cotton.
2. Of a mixture of equal parts of gun-cotton and nitrate of potash.
3. Of a mixture of 40 parts of gun-cotton to 60 parts of nitrate of ammonia.
4. Of nitro-glycerine 91 parts, and 5 of ordinary blasting powder.

TABLE I.

DESIGNATION OF SUBSTANCE.	CO	CO_2	H	N	O	C_2H_4	HS	TOTAL VOL. LIT.
Fine Gun-cotton	234	234	166	107	....	....	....	741
Gun-cotton and Nitrate of Potash	234	171	166	109	45	....	....	825
Gun-cotton and Nitrate of Ammonia	234	184	166	211	6	....	....	401
Nitro-glycerine	234	295	166	147	25	....	....	467
Ordinary Blasting Powder	64	150	4	65	....	4	17	304

Table I. shows in litres the volume of each of the gases per kilogramme of the substance under such conditions. In a second note, the same authors present the results obtained in decomposition of the same explosives under a tension near atmospheric pressure. These show the influences which the exterior conditions of reaction exert on the nature of the products. They give information as to the nature of the gases which may be expended in mines in the case of failure of detonation. In some cases the explosive, simply inflamed by the priming, fuses slowly under weak pressures.

TABLE II.

DESIGNATION OF SUBSTANCE.	NO_2	CO	CO_2	H	N	C_2H_4	TOTAL VOL. LIT.
Pure Gun-cotton	189	237	104	45	83	7	565
Gun-cotton and Nitrate of Potash	71	58	57	8	7	....	196
Gun-cotton and Nitrate of Ammonia	122	65	108	12	112	....	414
Nitro-glycerine	218	162	58	7	6	6	452

Table II. gives the volume in litres of each of the gases per kilogramme of the explosive. It will be seen that this mode of decomposition liberated binoxide of nitrogen and carbonic oxide.

† Schoen, "Der Tunnelbau," p. 67.

‡ Hill on Explosives, p. 48.

As to the general properties of gun-cotton, it is said that gun-cotton has been rejected as an explosive in Austria after twelve years' testing, because of its instability. Abel claims that this resulted from impurities in manufacture. Compressed gun-cotton has the disadvantage, as compared with dynamite, that it is not plastic, does not go well into rocky and uneven bore-holes, and cannot be compressed into place. Volume for volume, the compressed gun-cotton cartridges weigh less than dynamite, hence larger bore-holes are required. The cartridges being rigid and stiff, there are air spaces around them which not only by dilution lessen the power of explosion, but also decrease the tension of the gases set free. Gun-cotton has the advantage over nitro-glycerine that it does not freeze, and hence requires no thawing out, but a comparison of its general qualities as a blasting agent with those of nitro-glycerine and its dynamite compounds, is in favor of the latter.

English manufacturers have added oxidizing salts, such as the nitrates of ammonia, potash, soda, baryta, strontia, etc., to render the gases resulting from the explosion of gun-cotton less obnoxious. The nitrates of ammonia and soda, and, to a certain extent, of strontia, are deliquescent, and all the nitrates except that of baryta are very soluble, and interfere with the manufacture, besides giving bad odors in underground work. It is claimed that the mixture of gun-cotton with salts is not as sensitive to concussion as dynamite, hence that an exploder of extra strength is required.

Tonite.

Tonite consists of finely divided or macerated gun-cotton compounded with about the same weight of nitrate of baryta. This compound is then compressed into candle-shaped cartridges, formed with a recess at one end for the reception of a detonator composed of the fulminate of mercury. The cartridges are generally made water-proof, and the density of the compound is such that it takes up about the same space as dynamite, and about two-thirds the space of gun-cotton. It is claimed that tonite is an exceedingly safe compound to handle and transport, and that for the same weight, tonite is about thirty per cent stronger than gun-cotton. It has been much used in England, and is coming into use in the United States. (See, for fuller descriptions of "Tonite," article from "The Engineer," published in Van Nostrand's Magazine, vol. 19, 321. Also see vol. 18, p. 561. Also, for a set of tests showing very favorable results for this explosive, see the "Mining and Scientific Press," San Francisco, Aug. 27, 1881.)

Nitro-Glycerine.

Nitro-glycerine (or Glonoine), discovered in 1847 by Sobrero, is the most important of all explosive compounds at the present day. Sobrero did not make any practical application of it, and it was not until 1863 that Alfred Nobel brought it into general use as a blasting agent. His first patent for it in America is dated October 24th, 1865. The interest in his American patents was assigned to the United States Blasting Oil Company, represented by Tal. P. Shaffner. These patents for nitro-glycerine applied as a blasting agent are now (1882) held by the Giant Powder Companies. Among the first men in America to encourage the introduction of nitro-glycerine was Mr. Thos. Doane, who, when acting as Chief-Engineer of the Hoosac Tunnel, in 1866, caused Shaffner to make a number of trials there with the (then) new blasting agent. These trials were eminently successful, and ultimately led to the permanent adoption of nitro-glycerine in place of black powder in the tunnel, a factory being established for its manufacture at North Adams, Mass., by Geo. M. Mowbray, who also is noted as one of the first to experiment with nitro-glycerine in enlarging the bore-holes of oil-wells, near Titusville, Pa.

Among published documents on the subject, the earliest full account of the use of nitro-glycerine in blasting in America is given by Mr. E. P. North, in a paper read before the American Society of Civil Engineers, March 4th, 1868, on his experience in "Blasting with Nitro-Glycerine on the New Canaan Railroad."

Nitro-glycerine is a light yellow, clear, oily liquid, odorless, has a pleasant, sweet taste, is poisonous when inhaled, swallowed, or introduced into the body through the pores, producing headache and sickness. Its specific gravity is 1·595 to 1·6; it freezes when clear and transparent, according to Hill,* at 39° to 46° F. (about 10° C.); Trauzl † gives the freezing-point of ordinary commercial nitro-glycerine as 8° to 10° C. (46° to 50° F.); Mowbray ‡ gives 45° F. (about 7° C.) for his own product. About 8° C., or 46° F., can be taken as a safe figure.

Nitro-glycerine is dissolved with difficulty in water, readily in ether, pyroligneous spirit, or alcohol, the solution being non-explosive. Pure nitro-glycerine is not sensitive to friction or moderate percussion. If placed upon an anvil and struck with a hammer, only the particle receiving the blow explodes, scattering the remainder.

Experiments § have shown that pure nitro-glycerine, confined in vessels of tin, glass, and wood, did not explode when dropped from a height of 85 feet (26 metres) upon rock.

On the other hand, it should be borne in mind that this can only be affirmed positively as to pure and well-washed nitro-glycerine, in which there is no tendency to decomposition. There is a case on record of the explosion of a can of nitro-glycerine at Yonkers, N. Y., which resulted from its being struck with a stone thrown by a boy. Further, though, in the experiments noted by Schoen, nitro-glycerine did not explode when dropped from a height, it was, in the experiments referred to, enclosed in vessels of tin, glass, and wood. It now seems to be well established that nitro-glycerine enclosed in metallic vessels, especially in those of iron, is liable to explode when the vessel is struck by a sharp blow.

Hill, ‖ however, on the question of its storage and transportation, advises keeping nitro-glycerine in large earthen jars, with a layer of water over it. If it is to be transported, he advises freezing it, and carrying it in the frozen state, when it is far safer. ¶ That nitro-glycerine, when frozen, is difficult to explode, was probably first practically (though involuntarily) demonstrated by W. P. Granger, in the winter of 1867–'68. (Experiments have since unquestionably shown, however, that if the exploder used be sufficiently strong, even frozen nitro-glycerine can be exploded. See p. 72.) Mr. Granger was at the time acting as superintending engineer of Hoosac Tunnel, and Mr. Mowbray was just beginning the manufacture of nitro-glycerine for the tunnel. It was then the general impression that nitro-glycerine was most dangerous when frozen.

Mr. Granger received from Mr. Mowbray ten cartridges to take in his sleigh over the mountain to try their effect at the east end, and they were carefully packed before starting in a box with sawdust, after being warmed to 90° F. (32° C.). In driving over the mountain, the sleigh was upset and the cartridges spilled out of the box into the snow. By the time Mr. Granger got his mishap rectified and the cartridges gathered up, he found, to his dismay, they were frozen; however, risking the result, he replaced them frozen in the box, and drove on in safety. Arrived at the east end, it was found, on applying a charge of the frozen nitro-glycerine, that it would not explode, and could not be made to without first thawing it out; and this circumstance first pointedly illustrated the fact, afterward abundantly confirmed by experience, that nitro-glycerine, when fully congealed, is difficult to explode. For transportation, it should be put in strong tin cans holding about 45 or 50 pounds. Each can should be paraffined on the inside, and have passing vertically through the centre a tin

* On Explosives, p. 31. † "Die Dynamit, ihre Eigenschaften und Gebrauchsweise," p. 12 (1876).

‡ On Trinitro-glycerine, p. 82. § Schoen, "Der Tunnelbau," p. 68. ‖ On Explosives, p. 33.

¶ See also, on the transportation of nitro-glycerine, Mowbray on Trinitro-glycerine, p. 70.

tube, so that freezing or thawing may be more easily accomplished. All vessels in which nitro-glycerine has been kept should be destroyed when not wanted for the same use, as the nitro-glycerine is not easily washed off.

(With regard to the storage, etc., of nitro-glycerine, see p. 94.)

Pure nitro-glycerine does not spontaneously decompose* at any ordinary temperature, but if it contains free acid, decomposition is apt to occur. No instance has yet been noticed of the spontaneous decomposition of properly made and purified nitro-glycerine.

With increase of heat at 212° F. (100° C.), decomposition does not occur, but at 320° F. (160° C.) red vapors are evolved, and at 356° F. (180° C.), its firing point, sudden decomposition, accompanied by vehement explosion, ensues.

(The firing-point is maintained by some to be 360° F. rather than 356°.)

Nitro-glycerine is composed of carbon, hydrogen, nitrogen, and oxygen. Its formula is (Hill), $C_3H_5N_3O_9$ or $C_3H_5(NO_2)_3O_3$—this is trinitrin; monitrin, $C_3H_7(NO_2)O_3$, and dinitrin, $C_3H_6(NO_2)_2O_3$, occur when thorough conversion into trinitrin is not effected in manufacture, but the nitro-glycerine in ordinary use and of which dynamite is made is the trinitrin. The explosive force of nitro-glycerine undoubtedly results from the sudden production of watery vapor, carbonic acid, and nitrogen gas at a very high temperature, by a union of the oxygen present in the nitric acid, with the hydrogen and carbon of the glycerine; in other words, the oxygen of the nitric acid plays the part in nitro-glycerine which the oxygen of the nitric acid in nitre plays in ordinary gunpowder. Now, in trinitro-glycerine or trinitrin, there is a slight excess of oxygen present, while in dinitro-glycerine there is a considerable deficiency, by reason of which, what we may call the combustion of the carbon and hydrogen would be incomplete in the latter case; the combustion would be imperfect, and the force developed therefore less, just as it would be in gunpowder which contained too small a proportion of nitre.

The gases evolved, when complete explosion is effected, are, according to Schoen,† carbonic acid, nitrogen, oxygen, and water. The gases are given by Mowbray,‡ according to an analysis of M. L. Hole, as,

Carbonic Acid	45·72
Binoxide of Nitrogen	20·36
Nitrogen	33·92
	100·00

Trauzl § gives the gases as "chiefly carbonic acid and nitrogen," mixed in such proportions as not to be dangerous on inhalation. But when incomplete combustion takes place, carbonic oxide and oxides of nitrogen are formed, which are injurious, and it is owing to the fact that careless or ignorant firing is apt to be attended with incomplete detonation of the nitro-glycerine, that gave rise to the early misconception that the gases evolved were dangerous. This error has, however, been corrected by increased familiarity with the glycerine compounds. The explosion of 1 gramme (0·035 oz.) of nitro-glycerine at the temperature of 32° F. (0° C.) and barometrical pressure of 760 mm. (29·922 inches) gives 2000 cub. ctm. of gases which exercise a theoretical pressure of 26,000 atmospheres, corresponding to a theoretical effect of 400,000 kilogrammetres, or 2,893,000 foot-pounds. The temperature, on explosion of the gases, is placed at 9392° F. (5200° C.) (Trauzl.)

* Hill on Explosives, p. 31. † Schoen, "Der Tunnelbau," p. 69. ‡ On Trinitro-glycerine, p. 64.
§ "Explosive Nitrilverbindungen insbesondere Dynamit und Schiesswolle."

It is not within the province of this work to describe in detail the process of manufacturing nitro-glycerine. There are various patent processes: references to Nobel's and others will be found in Table 13, at end of this chapter. A patent for an "improved method of manufacturing trinitro-glycerine was also taken out by George M. Mowbray in 1868, the essential characteristic of which was, that the acids and nitro-glycerine were stirred and mixed by a current of air blown up through the mixture for the purpose of cooling the same, and to convert any hyponitrous acid in the mixture into nitric acid. Those desiring to study the manufacture of nitro-glycerine will find the process described in Hill, "On Explosive Compounds," and in G. M. Mowbray's work on "Trinitro-Glycerine."

The Detonation of Nitro-Glycerine.

Nitro-glycerine is, in fact, emphatically a detonating, not an igniting, compound. In other words, it is an explosive of the first order. As explained (p. 96), its full effect can only be completely brought forth by the shock caused in exploding some other explosive compound in sufficiently close proximity to it, so that the concussion effected by the latter shall induce a sympathetic explosion, or rather detonation, in the nitro-glycerine itself. This effect can be reached, but only partially, by the use of ordinary gunpowder. Strong fulminating caps are the best, and these are now manufactured expressly for the purpose (p. 91), and they are fired by either an ordinary fuse or by electricity, their detonation causing that of the body of nitro-glycerine in which they are enclosed.

After the first discovery of nitro-glycerine in 1847 by Sobrero, some fifteen years were suffered to elapse before it was practically attempted to apply it in blasting. During the Crimean war, attempts were made by Profs. Sinin and Jacobi to apply nitro-glycerine in torpedoes, but without avail, owing to the want of some proper means of exploding it. Alfred Nobel's father and brother were engaged in these experiments, and he himself, then but a youth, took his first lessons on the subject. From the close of the Crimean war, up to 1862, no further like efforts were heard of. In 1862, however, Alfred Nobel, then an engineer at Stockholm, commenced experimenting anew. Up to that time, it had not been demonstrated that nitro-glycerine could be exploded otherwise than by firing or igniting it in some form—that is to say, exploded in mass; for it was known that if spread on an anvil and struck, *the portion struck* would explode. Also at this time, the explosion of fulminates, especially in gun-caps, was known, but with a gun the application of a fulminate was to induce and transmit *ignition*, not *shock*. The earlier nitro-glycerine primers were made to be rubbed like a match; no one thought of using a cap to explode a thing that would hardly even burn. Touch nitro-glycerine with a match or a red-hot iron, and it ceases to burn when the match or iron is withdrawn. This, however, must be taken as a very general assertion. The accidental explosion at Bergen Cut, N. J., Newark R. R., is said to have been caused by the application of red-hot iron to *frozen* nitro-glycerine.

Now, Nobel knew that if nitro-glycerine were heated up to a certain point, it would explode. The difficulty was to thus heat it in a blast-hole; it occurred to him that gunpowder might be applied. He accordingly mixed nitro-glycerine with gunpowder, and applied fire; the mixture burned like gunpowder, but more slowly, and yet more rapidly than nitro-glycerine alone. Still, the nitro-glycerine was not exploded—*i. e.*, detonated—it was simply burned. On trying the mixture in bore-holes, the effect is thus described by Nobel in his earliest papers on file in the Patent Office* (Patent No. 50,617, granted October 24th, 1865): "By mixing it with gunpowder, gun-cotton, or any other substance developing a rapid heat, nitro-glycerine, being an oil, fills the pores of gunpowder, and is heated by the latter to the degree of its explosion. Gunpowder treated in this way, can take up from 10

* United States.

to 50 per cent of nitro-glycerine, and develops a greater power with a lesser quickness of explosion."

In experimenting with this mixture, it was observed that occasionally the effect was remarkable; the disruptive force seemed to be many times greater than usual. The hardest and toughest rock was broken into fine fragments, down to and beyond the bottom of the bore-hole; now, this effect was different in kind and extent from any thing ever witnessed before. The circumstances attending these exceptional blasts being noted, it was soon found they occurred in *hard rock* with *strong tamping.* Nobel then made trials accordingly, and found at length that he could produce such blasts at will; it was only necessary to make the confinement sufficiently tight and strong. Here is the origin of the heat and pressure necessary. The next step was to try liquid nitro-glycerine, and see if it also could be exploded in this way. This, Nobel succeeded in doing, and thus describes it in the application for his American patent: "Simply by a fuse. This will do in a closed space and under sufficient resistance, but if the gases of decomposed nitro-glycerine are enabled to escape before they accumulate to such a pressure as to effect the necessary *impulse of explosion*, the nitro-glycerine is slowly decomposed, and the fire generally goes out before the whole is consumed." This method, however, was so uncertain that it was never used in practice.

We thus see that Nobel now had his idea of an "*impulse of explosion.*" This he soon followed with the next step—*i. e.*, putting his main charge of gunpowder mixture in a tube and surrounding it with gunpowder—setting fire to the gunpowder, and by its explosion, exploding the main charge. This seems to be the first instance of using a typical "exploder." The process Nobel used was as follows: he first filled a zinc tube with gunpowder, then poured in all the nitro-glycerine it would hold, and corked it. This cartridge he put into the bore-hole, cork downward, and then filled the space about it with gunpowder, inserted the fuse into the gunpowder, and tamped as usual, except that the blows on the tamp next to the charge were very light. The fire of the fuse exploded the gunpowder, and this explosion was sufficient to cause the detonation of the nitro-glycerine mixture in the cartridge. Although this arrangement gave a result very inferior to that of the process subsequently perfected, still it was considered a great improvement on common blasting powder, and went into actual use at once, and continued in use, it is said, in certain localities in Europe, after the better mode was known. There will be found a report on the early use of nitro-glycerine, by B. Turly, Mining Engineer, in Dingler's "Polytechnisches Journal," vol. clxxi, 1864, p. 443, CVIII. In this report, Mr. Turly speaks of the above application of the zinc cartridge, etc.

About this time, Nobel further found that he could explode liquid nitro-glycerine in this same way, as well as the mixture. An article in the "Moniteur Scientifique du Docteur Quesneville, Journal Mensuel," Paris (3d series, vol. vi., March, 1876), says, p. 250: "The first experiments made with a mixture of nitro-glycerine and of ordinary powder showed the great explosive force of this liquid, but the true era of nitro-glycerine dates only from 1864, the time when a charge of pure nitro-glycerine was made to explode by means of a very feeble charge of ordinary powder."

Also in the memoranda to Nobel's original American patent occur these words: "There are many means of obtaining this impulse of explosion, such as by combining nitro-glycerine or analogous substances with gunpowder, gun-cotton, or similar substances; not as shown above (*i. e.*, in *mixture*), but separately; as, for instance, gunpowder in tubes and nitro-glycerine outside, or *vice versa*," etc., etc. (see patent).

Having now reached the fact that nitro-glycerine, either in the liquid form or in mixture with gunpowder or gun-cotton, could be detonated by an initial explosion, it only remained to reduce this exploder to its simplest and most effective form. This was

first done where gunpowder was still used for the exploder, by (in the words of the patent) "reducing the quantity of gunpowder or like acting substance to the proportion of a small burner, consisting of a tube of glass, paper, or other material, which is filled with gunpowder or similar substance introduced into the nitro-glycerine, and connected with a fuse, when its explosion gives to the nitro-glycerine the requisite impulse."

This completed the invention, or rather practical application, of nitro-glycerine as a blasting agent. What remained to be done was simply to improve the methods of firing. Now, it may be asked how gunpowder, which is an *igniting explosive compound*, can be thus applied in effecting the detonation of a *detonating compound*. The rationale of the process is this: nitro-glycerine, when fired by an exploder composed simply of gunpowder, undoubtedly detonates, but complete detonation is not in general effected. The explosion of the gunpowder heats by impact the nitro-glycerine immediately contiguous to it; this portion of the nitro-glycerine is thus exploded or detonated, and its detonation is propagated through the mass of the nitro-glycerine charge. But experience showed that great heat and pressure were requisite to effect a complete detonation, so that subsequently Nobel caused regular fulminating caps, fitted to the purpose, to be made, and these have since been the only kind of exploders in general use. Even with these (see p. 92), care must be taken to have the charge of fulminate sufficiently strong that the shock of its detonation may instantaneously affect the whole mass of nitro-glycerine in the charge, otherwise there will be noxious gases developed from the residue.

We have thus traced the invention of Nobel's method of detonating nitro-glycerine, up from the simple mixture of gunpowder burned, to the regular and complete detonation of pure nitro-glycerine by exploding within it a small cap or exploder. The steps *seriatim* were:

(1) The mixture of gunpowder and nitro-glycerine, used like common powder.
(2) This mixture burned under strong confinement.
(3) Liquid nitro-glycerine burned under strong confinement.
(4) The mixture in cartridges surrounded by powder, and the powder exploded.
(5) Liquid nitro-glycerine in cartridges surrounded by powder, and the powder exploded.
(6) Liquid nitro-glycerine, or its mixtures, detonated.

Nitro-toluol, so-called, is prepared similarly to nitro-glycerine, ordinary commercial benzole being substituted for the glycerine, and nitric acid for the nitro-sulphuric acid, in the manufacture of the latter. Three parts of this compound is then dissolved in seven parts of nitro-glycerine, and the compound is called "nitro-toluol."

THE NITRO-GLYCERINE COMPOUNDS.

Dynamite or Giant Powder.

Dynamite was first introduced into general use in Europe by Nobel, in 1867. The American patents were originally taken out by him in 1868, and are now held by the "Giant Powder Company" and the "Atlantic Giant Powder Company." It is hardly necessary to say that the "Giant Powder" used here is another name for dynamite.

The earliest attempt at mixing nitro-glycerine with a foreign inert substance, that was made in the United States, was by T. P. Shaffner, who in 1866 took out a patent for distributing the force of "nitroleum" in a drill-hole, by the admixture of sand, the nitroleum and sand being poured alternately into the hole. This mixture, however, lacked the essential qualities of a dynamite. Dynamite, broadly, is a mixture of nitro-glycerine with any dry, solid substance, whether mineral or vegetable, so pulverized or comminuted, and mixed in such proportions, that, on the one hand, the mixture contains sufficient nitro-glycerine to form

an efficient explosive compound, and, on the other hand, the proportion of absorbent used is sufficiently large to hold the nitro-glycerine against leakage or exudation. These proportions of nitro-glycerine and absorbent must, moreover, be so graduated that the mixture retains the pulverulent form.

The material preferred by Nobel as an absorbent was a kind of silicious earth known variously as silicious marl, tripoli, and rotten-stone.

The peculiar variety of this material best suited for the use is homogeneous, has a low specific gravity, and is composed of the remains of infusoria.

So great is the absorbent capacity of this earth, that when in a pulverized condition, it is claimed by Nobel that it will take up about three times its own weight of liquid nitro-glycerine, and still retain the form of a powder. Infusorial earth has so far been found to excel all other substances tried as absorbents, in possessing the requirements necessary; being composed of minute tubular shells, a mass of it is very spongy and compressible, its shells absorbing the nitro-glycerine by capillary attraction, and holding it with almost absolute security against filtration or compression. The secret of the safety of dynamite seems to be in its soft, pulpy, and at the same time mealy consistency, which gives it a complete cushion to prevent percussion.

Deposits of this silicious earth, technically termed "Kieselguhr," are formed in many places, notably in Hanover, in Europe, and in New Jersey, in this country. With regard to the composition of dynamite, it is commercially manufactured in the United States, in several grades, the leading ones being distinguished as No. 1 and No. 2.

According to the American patent specifications, No. 1 is composed of a mixture of seventy-five parts, by weight, of nitro-glycerine, and twenty-five parts, by weight, of infusorial earth.

(According to Hill,* the commercial dynamite No. 1 usually contains from 60 to 75 per cent of nitro-glycerine.) By the patent specifications, No. 2 contained originally forty parts, by weight, of nitrate of soda, six of rosin, six of sulphur, and eight of infusorial earth; these compose the absorbent or "dope," and to them, when properly prepared, were added forty parts of nitro-glycerine; these proportions, however, have since been varied from; also the nitrate of potash is found to be better than nitrate of soda, though more expensive.

Captain Alexander Mackenzie, of the Corps of Engineers, in a paper read before the Essayons Club, in February, 1874, describes the then process of manufacture at the works of the Atlantic Giant Powder Company, in Morris County, N. J. He says:

"The kieselguhr is prepared for use by first mixing it with a little water and then baking it into bricks. The object of this is to dry the earth more effectually. When required for use, the bricks are ground between rollers, carefully weighed into wooden tubs, and carried to the nitro-glycerine house. The absorbent for No. 2 is prepared as follows: the sulphur is pulverized in a revolving cylinder, at one end of which a blast of air enters, and, passing through, carries the powdered sulphur into a tight box. The nitrate (either of soda or potassa) is first dried thoroughly on an iron floor, then ground in a mill and passed into a box. The rosin is pulverized in a cylinder. The sulphur, nitre, and rosin are then mixed in proper proportions and carefully weighed into wooden tubs. . . . . The mixture of nitro-glycerine with these absorbents is made in wooden bowls lined with lead, ... and, after mixing, the powder is worked through ordinary sieves by hand." This gives the constituents of No. 2, as manufactured in 1874. The ingredients have since been much modified and the process is simpler. On p. 83 of this work will be found the composition of No. 2 dynamite as manufactured later.

* On Explosives, p. 36.

The explosive properties of dynamite No. 1 are those of the nitro-glycerine contained in it, as the absorbent is an inert body. Dynamite is brownish in color, resembling moist brown sugar. Its freezing-point is that of nitro-glycerine, 46° F. (about 8° C.), when it hardens to a whitish mass. If solidly frozen, it cannot be readily fired, but, if loose and pulverulent, it can be more easily exploded, although with diminished violence. Mr. E. P. North (M. Am. Soc. C. E.) has exploded a half cartridge of No. 1 when frozen, with two exploders, said to contain 27 grains of fulminate. The cartridge was in ice and had been left out of doors all night in winter. Geo. M. Mowbray says that 25 grains of fulminate will explode nitro-glycerine under any circumstances of temperature.

There is, in this connection, a point of some practical importance that should be noted by parties introducing dynamite on their works. When dynamite becomes thus frozen in winter, it is necessary for the blasters to thaw it out before using. Mr. North advises a dry house heated by steam, led through gas-pipe, for thawing it, the pipe being so arranged that the outlet can never be entirely closed. This is probably about the safest plan to adopt. (See p. 94 as to store-houses.)* When frozen dynamite is placed in ovens or kettles, on hot boilers, or when it is set up before a fire, and thus in any manner exposed to strong radiated heat, it is liable to explode; this has been proved by many so-called "accidents" or "unaccountable explosions" that have taken place. It is not certain that in most cases of this kind the cartridges explode with full force. To effect explosion, the heat has to be higher than the vaporization-point of the nitro-glycerine in the dynamite, because the latter is generally weakened before exploding. In many cases of this kind, the explosion has been of a very mild character, just sufficient to throw a man down, or to do some slight mischief. But this is only the case when *all* the cartridges placed for thawing are thus equally heated. If some are superheated, and others adjoining, which have been meantime thawed out, are not superheated, then a slight explosion in the heated ones is communicated to the others not previously weakened, and serious results follow.

In storing dynamite, exudation must be guarded against; for the same reason, it should not be made with too high a percentage of nitro-glycerine, especially when liable to be exposed to high temperatures, which tend to render the nitro-glycerine more fluid, and consequently liable to exude from the absorbent.

The firing-point of dynamite No. 1 is that of nitro-glycerine, about 356° F. (180° C.) (360° F. is said by some to be more nearly correct). If ignited, it burns strongly, evolving fumes and leaving a residue of silica. When complete combustion is effected in exploding No. 1, the gases evolved, being, of course, the same as with nitro-glycerine, are innocuous. Schoen † says on this point: "The inoffensive nature of the gases of combustion has been demonstrated by experience in mining and tunneling, even in cases where the means of ventilation are very inferior." It will be remembered that, under the description of nitro-glycerine, the gases evolved on complete combustion were given as chiefly carbonic acid and nitrogen. (Trauzl.)

The great advantage resulting from the use of No. 1 dynamite is that by it an immensely strong explosive is obtained, which is estimated to be about six times stronger than black powder in effective force, and yet which is unquestionably a safer material to transport, handle, use, or store than black powder. It is not sensitive to friction or moderate percussion. Alone, it may be hammered, crushed, or burnt with impunity. If set on fire, even in large masses, it will simply burn to ash.

To explode it, heat and strong percussion are needed. The explosion of gunpowder ad-

* The Giant Powder Company furnish portable furnaces for thawing out cartridges, in which the cartridges rest on shelves in a small jacketed chamber heated by water. Where these are not available, the cartridges may be thawed out in a bed of sand or hot ashes of about 100° Fahr.; or may be placed in a wooden box near the boilers in the boiler-house: in the latter case the cartridges should be turned from time to time. A practical and a reasonably safe method of thawing cartridges, sometimes used by miners, is for a workman to place several in his boot-leg while drilling. The natural warmth of the body will generally thaw out the cartridge by the time the hole is down.

† "Der Tunnelbau," p. 71.

joining will fire it, but not with certainty or with full effective force. It is therefore prepared for blasting by the insertion of a strong cap or exploder of fulminating powder,* which may be fired either by fuse or by the electric current. In fine, with regard to No. 1 dynamite (and by this term a mixture of 75 per cent of nitro-glycerine with 25 per cent of silicious earth is meant), it seems so far to be the general judgment in Europe and America that it is the best of the nitro-glycerine preparations, where great strength is required; and that it practically is so much safer than the liquid nitro-glycerine that it may be taken to be decidedly preferable.

Hill has suggested finely divided silica, obtained by precipitation from a solution of any of the alkaline silicates, as a substitute for silicious earth in the manufacture of dynamite, claiming that it has been used at the U. S. Torpedo Station at Newport, R. I., with good results. Mr. Hill says that the absorbent power of the precipitated silica is a little less than that of the natural earth, but that it retains the nitro-glycerine very well.

GIANT POWDER NO. 2.

Discussion of its Properties.

With regard to dynamite No. 2, and the other nitro-glycerine mixtures in which some lower explosive compound is substituted for part of the nitro-glycerine, acting at the same time as an absorbent, Mowbray says: † "To couple nitro-glycerine with chemicals such as nitrate of potash, nitrate of soda, chlorate of potash, mixed with carbonaceous matter, which require an instant's time to develop into gases, would be like attempting to quicken the electric current by coupling it to the velocity of a locomotive. . . . Under the usual conditions of blasting, the confinement of tamping with clay is insufficient to retain the explosive force of the nitro-glycerine until its tardy neighbors, resin, paraffine, saltpetre, chlorate of potash, nitrate of barytes, *et id genus omne*, have developed their force; or to recall the simile of the electric current, the sounding-board fifty miles away is giving the signal before the first puff of steam has reached the blast-pipe. Give four men a weight to lift which requires the united force of all of them to raise, the exertion of force by any one later than that of the others wastes the forces of all."

Hill ‡ says: "It is hard to see any advantage in these mixtures except that they are cheaper, and might be applied to uses where the great violence of the larger amount of nitro-glycerine is not needed, and yet a sharper explosive than black powder is wanted. It is improbable that any useful effect is obtained from any other ingredient than the nitro-glycerine. Those containing deliquescent salts (nitrate of soda, for example) are objectionable from their liability to exudation. All of them will be injured by water, which dissolves the salts, which are the principal ingredients. It is easy to see that the number of such mixtures that might be made is very great, for almost any dry salt or powder may be taken as an absorbent. No especial value would attach to any of them." And on page 60: "The available force they possess is that of the nitro-glycerine they contain, and it is evident that the less this is diluted with inert substances, the more effectively it can be applied. . . ."

Trauzl, § after speaking of dynamite proper (known in America as No. 1), says: "The other nitro-glycerine preparations are as susceptible to water as gunpowder; moreover, their explosive power is less than that of dynamite, inasmuch as they contain a less percentage of nitro-glycerine."

* See p. 92. † On Trinitro-Glycerine, p. 85. ‡ On Explosives, p. 88. § Explosive Nitrilverbindungen, etc.

On this same question, André says: * "Numerous attempts have been made to substitute combustible and explosive absorbent media for the incombustible silicious earth used in the preparation of dynamite. The purpose of this substitution is to increase the strength of the explosive by rendering the absorbent matters, which in dynamite are wholly inert, themselves explosive, to insure perfect combustion when the charge is fired, and to prevent the formation of noxious gases. The first of these objects is unattainable in the direction in which it is usually sought. No two explosive substances generate their gases with the same degree of rapidity, and it is obvious that if any two be mixed as independent explosives, the resulting compound cannot exceed in strength that of the more rapid substance, since the tardy forces of the other can take no part in the work done."

Thus we see it is argued that it is more than questionable whether the mixture of explosive salts with nitro-glycerine, as part of the absorbent, results in giving a compound of any greater effective strength than the same quantity of nitro-glycerine mixed with silicious earth would have. It is allowed that the salts certainly have explosive force, but the essential characteristic of nitro-glycerine as an explosive being its "quickness," the advocates of this theory assume that its effect is practically expended before that of its associates is fairly begun, and if so that their force is either spent through the spaces opened by the nitro-glycerine, or if the latter have failed of full effect, that the following force, so greatly inferior in strength, can do but little.

But the natural query arises, if these salts used in the bases of the various lower dynamites do not add to the effective strength of the compound, why admix them? One reason simply is, that an admixture of 40 per cent nitro-glycerine or less with infusorial earth alone is absolutely non-explosive. The author has been informed by Dr. Henry Morton, President of Stevens Institute of Technology, that, according to experiments made by him, the percentage of even fifty nitro-glycerine with fifty kieselguhr was essentially non-explosive. Assuming, therefore, that 40 to 50 per cent of nitro-glycerine mixed with silicious earth alone is non-explosive, and it being further assumed as an established fact that No. 2 dynamite has been manufactured in England with as low as 18 to 20 per cent, and in this country with a still lower percentage of nitro-glycerine, and found therewith to be not only an explosive compound, but a very effective one, far superior in force to black powder, we are led to the inference that the admixture of salts in the dope of No. 2 dynamite, and in the other nitro-glycerine compounds containing, on an average, about 50 per cent nitro-glycerine, does render such a nitro-glycerine compound explosive, or rather detonable, where it otherwise would not be, and that thereby their presence does serve to perform a useful function; the question that remains then simply is, do these combined salts in the base act passively or actively when the explosion takes place?—that is to say, do they by their presence in the base simply afford an absorbent for the liquid nitro-glycerine, which, by its nature, does not secrete the absorbed nitro-glycerine so closely as kieselguhr (or infusorial earth) alone does, or do they themselves participate in and augment the force developed when explosion is effected? Were the former object the only one sought by the admixture of salts in the base of No. 2, it would be open to question whether this object could not be attained at less expense by the substitution of cheaper components than soda, nitre, or saltpetre, etc., yet having the same *carrying* (if we may so express it) characteristics. But this object is not the only one subserved by the admixture of nitro-glycerine with explosive salts as absorbents.

We propose now to show, and it is submitted that the proof is based not on theory alone, but on facts, that not only do these salts in the base add appreciable strength to the explosive

* On Coal-Mining, p. 198. On p. 200, however, Mr. André quotes Mr. Linford's opinion to the effect that the explosive dope in Brain's blasting powder adds effective strength.

force of a nitro-glycerine compound, but they, in fact, add great strength to it; that the theory that their action is *nil* is erroneous, and founded simply on the plausible theoretical deductions and reasoning which we have above given; further, that this theory that they do not add strength is not in accordance with the facts nor based on fact.

The foregoing opinions from other writers on this subject have been given, in order that both sides might be fairly presented. Now, further to understand this point, let us quote Mr. André's* opinion as to lithofracteur (for the constituents of lithofracteur, see p. 87). Of it he says, that in lithofracteur, one of the cases seems to have been reached "in which the several ingredients are of such a nature and in such proportions that they are capable of acting toward each other in a manner that tends to promote rapid and perfect combustion;" that it is among the few of the compounds that have been tried which, "based upon a true chemical knowledge, have in a more or less satisfactory degree attained the end proposed, and are likely to assume in the future an importance which is not yet accorded to them."

Now, here it is that we have the key-note struck as to the true state of the case. Undoubtedly, as Mr. André suggests, the strength of the base depends on a careful proportion being observed in the admixture of its constituents. As a general position, we are safe in assuming that any explosive base will add some strength to a nitro-glycerine compound, and the strongest one will be the one compounded with the most intelligent regard to the chemical phenomena involved.

This "dictum" only, as it may perhaps be called (for we have already seen that Mr. André's general opinion is against the possibility of an explosive base developing effective strength), points to the true solution of the problem.

Now, let us bear in mind that the question simply is, whether a mixture of nitro-glycerine (which is essentially a detonating explosive compound) with an igniting explosive compound, will develop greater effective strength than the sum of the forces developed by the same compounds fired separately. We will show that a resulting force far greater than the sum of these forces is developed. Suppose we simply take nitro-glycerine and gunpowder—they are the leading types of the two classes. On this point, Prof. Charles F. Chandler, of Columbia College, New York, has said:† "Where gunpowder explodes in the ordinary manner, the explosion is slow and progressive, and produces a temperature much lower than that produced by nitro-glycerine, but when the gunpowder is exploded by nitro-glycerine its explosion becomes instantaneous, it becomes detonative, it occurs at a much higher temperature, produces a much larger volume of gas, and consequently develops a very much greater force than when exploded alone; consequently, the force developed by the explosion of a mixture of gunpowder and nitro-glycerine is equal to the sum of the forces developed by the nitro-glycerine and by the gunpowder when detonated, which last force is very much greater than the force of the gunpowder when exploded alone." (The foregoing opinion was directly on the following point, viz.: "If a given quantity of gunpowder explodes with a certain force, and a given quantity of nitro-glycerine explodes with a certain force, if the same quantity of nitro-glycerine and powder be mixed together and exploded by concussion, will the mixture explode with a force much greater than the sum of the force of the explosion of the two parts?") Now, as to the difference between a detonation and an explosion, the point will be found fully discussed, p. 96 of this work. There it will be seen that the difference essentially is that a detonation may be assumed to be an instantaneous explosion, induced throughout the whole mass of an explosive compound, while an explosion proper (in the restricted sense of the word) is the result of ignition

* André on Coal-Mining.

† Testifying as expert in the case of "The Atlantic Giant Powder Company *vs.* Treat S. Beach, *et al.*" (1873).

transmitted from grain to grain of the explosive. On the general question, Prof. Chandler says further: "The force exerted by an explosive agent when it explodes depends, first, upon the absolute quantity of gas produced, and, second, upon the increased quantity of gas due to the expansion or increased volume due to the high temperature. The expansion is in proportion to the temperature; the temperature, however, varies with the manner of the explosion, while the absolute number of heat units developed by a chemical reaction, as an explosion, is fixed. The temperature depends entirely on the time during which the reaction takes place. A pound of wood produces just as much heat when it undergoes oxidation or decay in a forest as when it is burned rapidly in a fireplace, but years elapse before the slow decay is complete, and the most delicate thermometer would hardly detect any increase in temperature during the combustion. With the aid of the bellows, the combustion in the fireplace is completed in a few moments, and a white heat is produced. Now, in the ordinary explosion of gunpowder, we have a comparatively slow combustion; a large amount of the gunpowder escapes combustion or fails to undergo combustion, until it is too late for it to accomplish any practical result in moving a projectile or in shattering rocks. Moreover, owing to the slowness of this combustion, a lower temperature is produced, and consequently the volume of gas at the moment of explosion is much less than it would be did the explosion take place more rapidly and develop a higher temperature. When gunpowder is mixed with nitro-glycerine and exploded, the combustion is much more rapid. It is called, by investigators of explosives, a detonation, to distinguish it from an ordinary explosion. Gunpowder undergoing detonation produces a much greater effect, therefore, than when exploded by itself in the ordinary manner; first, because it produces a much higher temperature; second, because it is more completely burned."

As to the amount of gunpowder unconsumed when gunpowder alone is fired, the experiments of Bunsen and Schischkoff showed that the waste in gunpowder is about 68 per cent of its own weight, only 32 per cent being utilized—that is to say, while about one third of the weight of gunpowder appears after the explosion, in the form of gas, carbonic acid, carbonic oxide, and nitrogen, about two thirds the weight appears in the form of solids, sulphate of potash, carbonate of potash, hyposulphite of potash, unchanged nitrate of potash, and sulphide of potassium—all of which compounds are solid at a red heat, but assume the form of gas at a considerably higher temperature.

This supposed utilization (if it may be so called) of the ordinarily unconsumed proportion of gunpowder, that is effected when it is fired in conjunction or combination with nitro-glycerine, is of course only one theory to account for the fact that, in combination with nitro-glycerine, gunpowder does undoubtedly, in spite of all theories to the contrary, develop enormously greater strength than when fired alone. Prof. Chandler says: "This is not the only possible explanation of the fact. It is known that very high temperature destroys chemical compounds, dissociating their elements. It may be that the temperature which prevails when gunpowder is exploded by nitro-glycerine, is sufficient to separate the elements contained in the potash salts combined with it, and thus greatly increase their volume."

Now, the above discussions give theories on either side of this question, but the tunnelman, as a general rule, is not so much interested in theories as in facts. The question is, What is the fact in this matter? Do explosive dopes or absorbents when mixed with nitro-glycerine, add to its effective, disruptive strength, or do they not? To practically test the question, the author of this work requested permission of the Atlantic Giant Powder Company to make a set of trials at their works at Drakesville, N. J. The permission was cordially acceded, and the trials were made in June, 1877. They were of three kinds, and will be described in order.

The first experiment was made with a block of iron having on its top surface a socket or half-hemispherical bore hollowed out, this socket having a diameter of four and a half inches. In this hollow an iron ball exactly fitted. When the ball was in place, of course half of it projected above the block. A channel cut in the block down the side of the hollow allowed the introduction of a fuse below the ball, without, however, preventing the latter from resting solidly in place. At the bottom of the socket (if we may so term it) was a powder-chamber one inch and an eighth in diameter and about one quarter of an inch deep. In this chamber, 4 dwt.* of common black blasting powder was placed, the ball placed over it, and the charge ignited by a piece of common safety-fuse. Result: on ignition of the charge, it did not throw the ball out of the socket, but raised it sufficiently to allow the gases to puff out. Second, 12 grains † (by weight) of nitro-glycerine were exploded in the same manner under the ball (except, of course, that in this case an exploder was attached to the end of the fuse, in order to explode the nitro-glycerine), and the ball was thrown 25 feet vertically in the air. Third, 4 dwt. of the same blasting powder and 12 grains of nitro-glycerine were together, by means of an exploder, fired under the ball: the ball was thrown up 75 feet. Now, it will be observed that the amounts of powder and nitro-glycerine used in the compound were the same as when they were used in separate charges.

Next, a mortar such as is shown in section in Fig. 13 was used. This mortar was of cast-iron, its bore 4 inches in diameter, with a steel disc, 3 inches thick, shrunk into the bottom so as to leave the bore 6 inches deep. The shot exactly fitted the bore, was 7 inches long, and weighed 28½ pounds.

At the centre of the inner end of the shot was a hollow cavity for the charge. Above the powder cavity there was a recess into which the exploder fitted, so as leave the fulminate of the cap in the powder-chamber. From the cap, through the centre of the shot to the outer end, was a small hole for the electric wires. This mortar was strengthened by heavy wrought-iron bands, shrunk on it, and it was bolted at an angle of 45° to foundation timber placed in the ground. In charging the mortar, the wires of the exploder were passed through the shot and the cap drawn to its place. The charge was then placed in its chamber, and held in place by a disc of thin paper pasted over it, within a recess prepared for it as shown in the figure. The shot was then lowered to its place in the mortar, great care being taken to have the shot and the bottom of the bore in close contact. The slightest opening between them was found to seriously affect the result. (See p. 112.) The charge was fired by a friction battery, and the distances to which the shot was thrown carefully noted from a series of distance-stakes along the line.

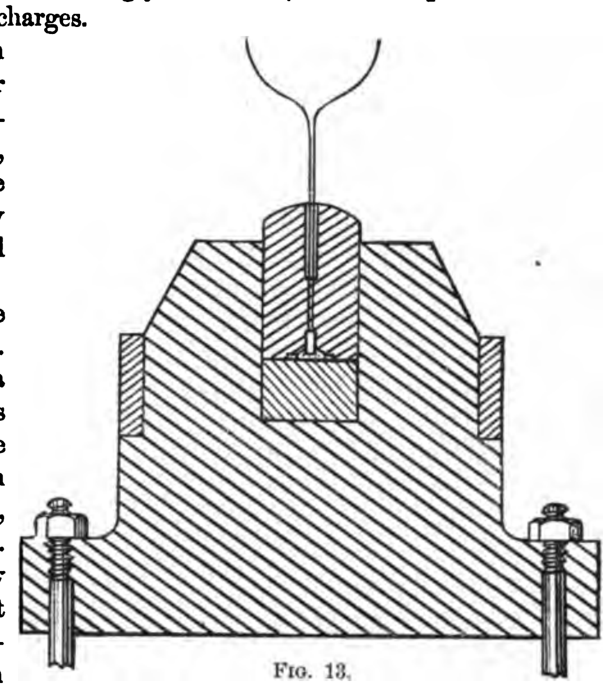


FIG. 13.
Mortar used in No. 2 Dynamite Tests.

In this mortar, trials were made with various nitro-glycerine compounds as follows:

* 1 dwt. = 1·535 grammes.

† 1 grain = 0·0625 gramme.

(1) Charge = 5 dwt. No. 2 dynamite. Ball thrown 620 feet.
(2) Charge = 48 grains nitro-glycerine. (This being the amount of pure nitro-glycerine contained in combination in 5 dwt. of No. 2 dynamite.) Ball thrown 358 feet.
(3) Charge = 5 dwt. rifle powder. (Hazard's American sporting powder, $1 per lb.) Ball thrown 248 feet.
(4) Charge = 5 dwt. XX dynamite. (This dynamite was composed of only 4 per cent of nitro-glycerine with an explosive base.) Ball thrown 256 feet.

The latter two experiments were simply to show that a dynamite holding a very small percentage only of nitro-glycerine will, when mixed with an explosive base, give a blasting powder exceeding the best rifle powder in strength. It is, however, with the main experiments 1 and 2 that we are here concerned. As to tests of this nature made in a mortar, it has been objected that they do not give accurate results, on the general ground that explosive compounds when fired develop, according to their nature, either mainly projectile or disruptive effects. Thus, in order that a ball of a given weight should be set in motion by a given total force, that force must be applied during a definite interval of time; if the same total force is applied during a less time, it cannot produce the same velocity, but will be expended, as is all arrested motion or force, in heating the substances by which the motion is arrested. Thus, when a rapidly exploding material is fired in a mortar of the above description, a large part of its force is consumed in heating the shot and mortar in the same manner that a bar of iron is heated when violently struck with a hammer. On the other hand, an explosive which developed the same total force, but burned a little more slowly, would expend relatively all its force in giving motion to the ball, as during the passage of the ball from its seat to the mouth of the mortar or cannon, it would be impelled by a constantly accelerating force induced by the more complete combustion of the explosive. Again, an explosive developing the same or even greater total force, but exploding quicker, would produce less projectile velocity in the ball; while, again, this very suddenness, which is unfavorable to the maximum projectile effect, would be favorable to bursting or fracturing results, since the resisting forces which are there to be overcome also involve the element of time. In other words, this reasoning, on general grounds, would tend to indicate that the mortar test is a proper measure of ballistic force, but not so accurate a gauge of disruptive fôrce in explosive compounds not similarly constituted. But the application of this reasoning is seen best in gunnery proper, where the distance traversed by the ball from breach to muzzle is of moment. With a mortar such as is above described, where the diameter of the bore is four sevenths of the length of the bore, the charge of explosive is so small relatively to the bore of the mortar, and the retention of the gases so slight (comparatively speaking), that the test may be taken as an approximate indication at least. Moreover, in the first set of tests with the half-hemispherical socket and ball, the same comparative result, it will be remembered, was reached with no bore whatever. There, as soon as the ball was raised from its seat the smallest fraction of an inch, the gases had a vent.

In order, however, to test the question from a wholly different stand-point, a third apparatus was tried, which we will term a pressure-gauge. It consisted, as shown in Fig. 14, of a vertical steel pin C. 6¾ inches long, 1½ inches in diameter, enlarged at the top to 4 inches. This pin weighed 8½ lbs., and it slid vertically in an iron block E, which block was bolted by G G to an iron foundation F, weighing some 1200 lbs. The pin rested upon a small truncated cone D of lead, which itself rested upon the foundation. Great care was taken to have the lead cones homogeneous in purity, and of exactly the same dimensions. The machine was operated by charging the same ball or shot that was used in the mortar experiments. It was

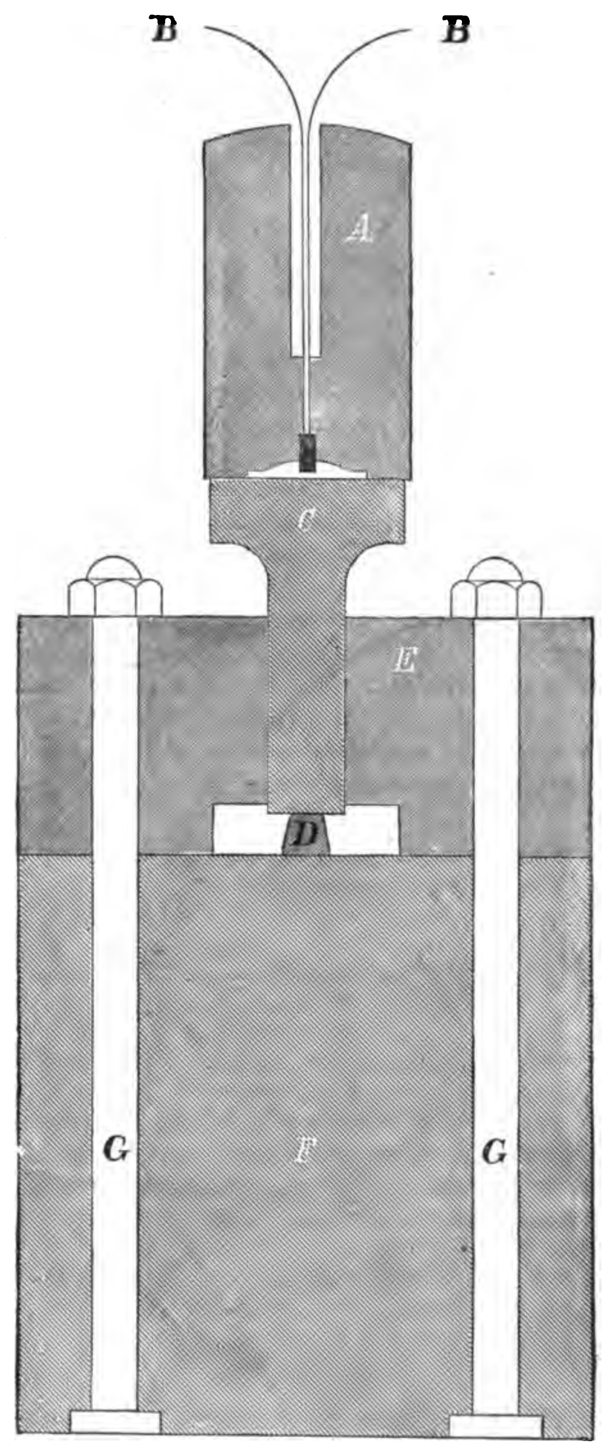


FIG. 14.
Pressure Gauge. Scale 3" = 1 foot.

then placed, A, upon the steel pin, and fired in the manner already above described in the mortar experiments, through the wires B B. The comparative strength of the different compounds tested was measured by the compression of the lead effected at each shot.

Repeated trials with this pressure-gauge showed conclusively that not only the compression of the lead was far greater when an explosive base was used in conjunction with nitro-glycerine, than the sum of the compressions effected by the same amounts of nitro-glycerine and base when fired alone, but so much greater that there could be no question of the principle established.*

These tests, in June, 1877, were conducted by the author alone. In order, however, to substantiate the results obtained, he arranged to repeat them in September, 1877, in the presence of Prof. B.W. Frazier, Professor of Mining and Metallurgy at the Lehigh University, Mr. Frank L. Clerc, Chemist to the Lehigh Zinc Works, and Mr. Frank P. Howe, Mining Engineer. These gentlemen were so kind as to give their assistance as experts, and the second set of experiments were made under the auspices of the Lehigh University, the university apparatus, scales, etc., being kindly tendered.

This time, the ball and socket and the mortar tests were omitted, the pressure-gauge being alone used. It was arranged precisely as above described.

The tests in detail were as follows;† the measurements being in inches and decimals of an inch (1 inch = 2·54 ctm.), and the weights in grammes and decimals of a gramme (1 gramme = 0·0352758 ounce avoirdupois).

The small truncated cones of lead averaged in diameter at top, 0·815″; at bottom, 0·797″; mean diameter = 0·806″. The height of the cone was in each case carefully measured before and after compression by a micrometer screw measuring to thousandths of an inch.

Each separate test was repeated a sufficient number of times to eliminate errors of accident; the average results only are herewith given:

I. The first trial was to test the strength of the exploder or cap used in all subsequent experiments with nitro-glycerine or its compounds.

Charge—one exploder.

Mean height of lead before firing	0·929″
" " " after "	0·754″
Compression	0·175″

II. The second trial was to test whether in ordinary No. 1 dynamite (or giant powder), composed of 75 per cent nitro-glycerine and 25 per cent infusorial earth, there was any appreciable loss of power by the absorption of the nitro-glycerine in the infusorial earth.

(A) Charge, 1·5 grammes No. 1 dynamite.

Mean height of lead before firing	0·932″
" " " after "	0·194″
Compression	0·738″

Next, the amount of pure nitro-glycerine contained in 1·5 grammes No. 1 dynamite was taken.

* Mr. T. Shaw, of Philadelphia, makes differential mercury column gauges registering explosive force up to 40,000 lbs. per square inch. These gauges are used for black powder; ordinary blasting giving 22,000 lbs., and sporting grades 40,000 lbs. See also reference to apparatus used by General Henry L. Abbot, Engineering and Mining Journal, New York, June 17, 1882, vol. 33, p. 312.

† It will be observed that in the experiments in June, Troy weights were used. In September, the metric weights from the University were adopted.

(B) Charge 75 per cent of 1·5 grammes = 1·125 grammes.

Mean height of lead before firing	0·933″
" " " after "	0·180″
	0·753″

Therefore,

(C) Compression exerted by No. 1 dynamite	0·738″
" " nitro-glycerine alone	0·753″
In favor of nitro glycerine alone	0·015″

This difference is very small; still it would appear sufficient to indicate, if not a *practical* still a positive and *appreciable* diminution of the effective power of the nitro-glycerine by the absorbent. Practically, about 75 has been found, by long practice, to be the highest percentage of nitro-glycerine that can be held by kieselguhr without exudation, and it may be assumed, for all practical purposes, that the full effect of the nitro-glycerine is attained.

III. The third trial was with the same percentage (75) of nitro-glycerine as in II., but with an explosive base or dope substituted for the 25 per cent of kieselguhr.

Charge, 1·5 grammes.

Nitro-glycerine	75 per cent.
Nitrate of potash (saltpetre)	20 "
Sawdust	5 "

The nitrate of potash was finely divided, and had been carefully dried. The sawdust was of pine, and it also had been dried.

Mean height of lead before firing	0·932″
" " " after "	0·162″
Mean compression	0·770″

We therefore have from

II. (A) Mean compression	0·738″
III. " "	0·770″
In favor of III	0·032″

Where one is dealing with explosive compounds, we must remember that their manufacture is simply a question of synthetic chemistry, and that given certain explosive reagents, that mixture of them will develop the greatest effective force in which the several constituents are combined in such proportions as to leave no excess of one reagent over another. Repeated trials seem to have established as to the explosive dope, that where sawdust and saltpetre are used, the best proportions are 1 of sawdust to from 3 to 4 of saltpetre. In the tests made in June, the author used 1 sawdust to 3 saltpetre; in September (the tests we are now describing), 1 sawdust to 4 saltpetre was used, and the results obtained were very close to each other. Theoretically, the proportion 1 to 3 seems the more correct, for, assuming the ideal reaction to be

$$48(KNO_3)+5(C_{12}H_{20}O_{10}) = 24(K_2CO_3)+36CO_2+50H_2O+48N,$$

we see that a theoretically perfect mixture (if the above reaction be correct) would call for 4848 parts saltpetre to 1620 parts sawdust, giving a proportion of 3 to 1.

IV. (A) Charge 1·5 grammes:

Nitro-glycerine	40 per cent.
Nitrate of Potash	48 "
Sawdust	12 "

Mean height of lead before firing	0·930″
" " " after "	0·227″
Mean compression	0·703″

Next, the amount of pure nitro-glycerine contained in 1·5 grammes of the above mixture IV. (A) was taken.

(B) Charge 40 per cent of 1·5 grammes = 0·6 gramme.

Mean height of lead before firing	0·930″
" " " after "	0·329″
Mean compression	0·601″

We therefore have from

IV. (A) Mean compression	0·703″
IV. (B) " "	0·601″
In favor of IV. (A)	0·102″

It was thus evident that great effective strength was added by the admixture of the dope. Moreover, this compression of 0·102″ is, in fact, much greater than it relatively appears to be, for we must remember that the compression effected is not in direct proportion to the force exerted—that is to say, if a cone of lead were struck and compressed by a certain force, and then a similar cone were struck with a force twice as great, the compression effected in the latter case would be less than double that shown in the former case, for the resistance would be greater as the molecules became more closely compressed.

The next trial was suggested by Mr. Clerc on the ground, "Given an explosive compound composed as in IV. (A) of

Nitro-glycerine	40 per cent.
Nitrate of Potash	48 "
Sawdust	12 "

what relation, in point of effective strength, does the dope bear to the nitro-glycerine?" After several trials with different weights of pure nitro-glycerine, it was found that a charge of 0·900 gramme of pure nitro-glycerine *gave practically the same compression as a charge of* 1·5 *grammes of the mixture* IV. (A) thus:

V. Charge 0·900 gramme pure nitro-glycerine.

Mean height of lead before firing	0·929″
" " " after "	0·229″
Mean compression	0·700″

or IV. (A)	Mean compression	0·703″
V.	" "	0·700″
	Difference	0·003″

Three thousandths is so small a difference that it may be disregarded; indeed, exact equivalent results would not be any more reliable. We therefore see that as the proportions of pure nitro-glycerine in IV. (A) and V. are as 6 : 9, that in IV. (A) the nitro-glycerine does two thirds of the work; in other words, that an explosive dope composed of 1 sawdust to 4 saltpetre, when mixed in the proportion of 40 parts of nitro-glycerine to 60 of dope, adds one half to the effective strength of the nitro-glycerine. This compound is the ordinary commercial giant powder (or dynamite) No. 2. The sulphur and rosin described above (p. 69) by Capt. Alex. Mackenzie as being used in the manufacture of No. 2 dynamite are now discarded. Sawdust and saltpetre are the only constituents of the dope, the sawdust giving the carbon and the saltpetre the oxygen necessary, while the nitro-glycerine present avoids the need of the sulphur ordinarily added to promote combustion.

Next, a trial was made with the XX powder that has since been largely introduced by the giant powder companies. This explosive is substantially founded on the principles described in the patent No. 183,764 of Egbert Judson (see p. 104 of this work). In it a very low percentage (6 per cent) of nitro-glycerine was used. The object of the trial was to see the strength added by the explosive dope, and also to compare this XX dynamite with ordinary rifle powder.

VI. (A) Charge 1·5 grammes XX powder.

Mean height of lead before firing	0·933″
" " " after "	0·335″
Mean compression	0·598″

Next, the amount of pure nitro-glycerine contained in 1·5 grammes of XX powder was taken.

(B) Charge 6 per cent of 1·5 grammes = 0·09 gramme.

Mean height of lead before firing	0·931″
" " " after "	0·668″
Mean compression	0·263″

(C) Charge 1·5 grammes "American Sporting Powder," of the Hazard Powder Company, fired simply with Bickford fuse without exploder.

Mean height of lead before firing	0·933″
" " " after "	0·876″
Mean compression	0·057″

(D) Same charge as (C), except that, instead of being ignited by a fuse, it was fired by an exploder with battery.

Mean height of lead before firing	0·933″
" " " after "	0·516″
Mean compression	0·417″

From these four tests, VI. (A), (B), (C), and (D), we see, first, that as between (A) and (B):

(A) Mean compression	0·598″
(B) " "	0·263″
In favor of (A)	0·335″

Now, the compression produced by the best rifle powder is, we see by (C), only 0·057 when it is fired by fuse, but when fired with an exploder as in D, it is probably in a measure detonated, and we then obtain an effect of 0·417; comparing (A) and D, we have,

(A) Mean compression	0·598″
(D) " "	0·417″
In favor of (A)	0·181″

But it is hardly necessary to call the attention of the reader to the fact that the best rifle powder is many times stronger than ordinary blasting powder; moreover, that a small quantity of rifle powder (1·5 grammes), fired by an exploder, would be detonated under the most favorable circumstances; yet even here, we see the XX powder developing far greater strength, though the percentage of nitro-glycerine is only six. It is claimed that this new XX brand of dynamite can be manufactured at a much lower cost than black blasting powder, and that it will do far greater work; and these tests appear to substantiate such a conclusion as to the question of greater strength.

The above six trials appeared to so conclusively demonstrate the fact that an explosive dope does add effective strength to a nitro-glycerine compound, that it did not seem necessary to pursue the question further.

Before concluding the trials, however, a set of successive tests were made, with gradually increasing charges of pure nitro-glycerine, to establish the pressure exerted by the several amounts of nitro-glycerine taken. This was done with the following results:

VII. Charge 0·200 gramme pure nitro-glycerine.

Mean height of lead before firing	0·933″
" " " after "	0·527″
Mean compression	0·406″

VIII. Charge 0·400 gramme pure nitro-glycerine.

Mean height of lead before firing	0·930″
" " " after "	0·414″
Mean compression	0·516″

IX. Charge 0·600 gramme pure nitro-glycerine.
Test No. IV. (B) above showed the mean compression with this charge to be 0·601″.

X. Charge 0·700 gramme pure nitro-glycerine.

Mean height of lead before firing	0·929″
" " " after "	0·285″
Mean compression	0·644″

XI. Charge 0·800 gramme pure nitro-glycerine.

Mean height of lead before firing...................... 0·933″
" " " after " .... 0·261″

Mean compression.............................. 0·672″

XII. Charge 0·900 gramme pure nitro-glycerine. Test No. 5 above showed the mean compression with this charge to be 0·700″.

XIII.* Charge 1·0 gramme pure nitro-glycerine.

Mean height of lead before firing...................... 0·931″
" " " after " .... 0·201″

0·730″

TABLE 9.

The mean results only of trials are given above. The following are the tests in detail, from which mean results were deduced in all trials:

	Original Height of Lead Cones.	Mean.	Height of Cones after compression.	Mean.	Compression.	Mean.
I Charge = 1 Exploder................	0·931* 0·929	0·930*	0·755* 0·754	0·755*	0·176* 0·175	0·175**
II. (A) Charge, 75 per cent nitro-glycerine, 25 per cent infusorial earth.........	0·931 0·933 0·932	0·932	0·198 0·192 0·193	0·194	0·733 0·741 0·739	0·738
II. (B) Charge, 1·125 grammes pure nitro-glycerine......................	0·933 0·933	0·933	0·181 0·179	0·180	0·752 0·754	0·753
III. Charge, Nitro-glycerine, 75.........; Saltpetre, 20.........; Sawdust, 5.........	0·932 0·933 0·931 0·933	0·932	0·166 0·158 0·156 0·169	0·162	0·766 0·775 0·775 0·764	0·770
IV. (A) Charge, Nitro-glycerine, 40.........; Saltpetre, 48.........; Sawdust, 12.........	0·932 0·930 0·930 0·927	0·930	0·225 0·230 0·220 0·232	0·227	0·707 0·700 0·710 0·695	0·703
IV. (B) Charge, 0·600 gramme nitro-glycerine................................	0·925 0·931 0·933	0·930	0·324 0·330 0·333	0·329	0·601 0·601 0·600	0·601
V. Charge, 0·900 gramme pure nitro-glycerine..........................	0·927 0·932	0·929	0·232 0·227	0·229	0·695 0·705	0·700
VI. (A) Charge, 1·5 grammes XX powder.....	0·933	0·933	0·335	0·335	0·598	0·598
VI. (B) Charge, 0·09 gramme pure nitro-glycerine..........................	0·931	0·931	0·668	0·668	0·263	0·263
VI. (C) Charge, 1·5 grammes American sporting powder, fired by fuse...........	0·933	0·933	0·876	0·876	0·057	0·056
VI. (D) Charge, 1·5 grammes American sporting powder, fired by exploder......	0·933	0·933	0·516	0·516	0·417	0·417
VII. Charge, 0·200 gramme pure nitro-glycerine..........................	0·933	0·933	0·527	0·527	0·406	0·406
VIII. Charge, 0·400 gramme pure nitro-glycerine..........................	0·930	0·930	0·414	0·414	0·516	0·516
IX. Charge given in IV. B...............	....	....	....	....	....	....
X. Charge, 0·700 gramme pure nitro-glycerine...	0·929	0·929	0·285	0·285	0·644	0·644
XI. Charge, 0·800 gramme pure nitro-glycerine................	0·933	0·933	0·261	0·261	0·672	0·672
XII. Charge given in V...................	...	....	....	....	....	....
XIII. Charge, 1·0 gramme pure nitro-glycerine..........................	0·931	0·931	0·201	0·201	0·730	0·730

* These latter tests from VII. to XIII., inclusive, were made in the endeavor to find compressions of the lead cones, corresponding to various definite charges of nitro-glycerine, so that, assuming the pressures exerted to be proportional to the charges of nitro-glycerine, a scale might be obtained by which to measure the relative pressures exerted by different explosive mixtures.

As to tests with the pressure-gauge, one objection * to their accuracy that has been made is that there is a recognized limit to the velocity with which force can be transmitted along a body. The velocity of sound in that body, in fact, expresses this limit. If a force is applied at a higher velocity, it is only transmitted in part, the remainder causing compression of the body and the development of heat. From this, it may be argued that blows, shocks, or explosions, acting with great velocity or suddenness, would be less fully transmitted, and so fail to produce their adequate effects, as compared with those less sudden, down to the limit of the velocity at which the bar would transmit sound. For this reason, it may be said that the pressure-gauge fails to give in full their just proportions to such shocks as those of pure nitro-glycerine and like bodies, whose suddenness of explosion would be much in excess of the transmitting velocity of an iron bar. But with the pressure-gauge, the bar through which the shock is transmitted, as we have seen, is only some inches long, and it is more than questionable whether any apparatus could be devised for measuring such tremendous forces as those developed by the detonation of nitro-glycerine compounds that would not be open to some slight criticism. Moreover, we undoubtedly have here three distinct sets of tests: those by the ball and socket, by the mortar, and by the pressure-gauge; and they all point conclusively to the same general result—*i.e.*, it was shown in the case of each set of tests that a compound of nitro-glycerine with explosive salts developed far greater effective strength than the sum of the forces developed by the several constituents alone, and this excess of strength is so great in the former case that we seem justified in assuming the principle.

Compounds of nitro-glycerine with a lower percentage of the latter than that contained in No. 1 dynamite must be bought, for use in the rocks, varying between easy rock, where black powder has hitherto been found to be most effective, and the opposite extreme of hard syenite, trap, or granite, where pure nitro-glycerine or No. 1 dynamite do their best work; especially are they of use in enlarging in tunnel-work, taking off sides, etc., etc., where they can be used with much greater economy than No. 1, the great strength of which is so apt to be wasted by ignorant workmen.

In fact, the lower dynamites are, perhaps, in many cases cheaper in tunneling even through the harder rocks, *when deep-hole blasting* is not used; but in wide headings driven by rock-drills with ten and twelve foot centre cuts, the work can only be effectively done with No. 1 dynamite, or, perhaps, the pure nitro-glycerine.

The lower compounds of nitro-glycerine (similar to dynamite No. 2) are known under **various names**, as lithofracteur, dualin, rend-rock, vulcan powder, glyxoline, Horseley's powder, etc., etc. They are all based on the general principles enunciated in the foregoing discussion of giant powder (or dynamite) No. 2. (See p. 88 for others, and Table 13, p. 99.)

The composition of No. 2 dynamite, as manufactured in this country, we have given. The following † are varieties of it made in England:

	Per cent.		Per cent.
Nitrate of Soda	69·00	Nitrate of Potash	71·00
Paraffine	7·00	Paraffine	1·00
Charcoal and Coal-dust	4·00	Charcoal	10·00
Nitro-glycerine	20·00	Nitro-glycerine	18·00
	100·00		100·00

* Prof. Henry Morton, in his testimony as expert in the suit of "Atlantic Giant Powder Company *vs.* George M. Mowbray *et al.*" Another objection to the apparatus described on previous pages is that they probably give less than the full force due to the explosive, there being a double loss by reason (1) that the carbonic oxide is not further oxidized to carbonic acid, and, (2) the full expansive force of the heat of combination is not utilized. An apparatus fully confining the gases of explosion would doubtless show greater pressures.

† "Report of Select Committee of House of Commons on Explosive Substances," June, 1874.

Lithofracteur.

Lithofracteur is a nitro-glycerine preparation made by Krebs Bros. & Co., in Cologne, claimed to be first manufactured by Engels, in 1866. According to Trauzl (1870), it is composed of—

	Per cent.
Nitro-glycerine	52
Infusorial Silica and Sand	30
Carbon	12
Nitrate of Soda and formerly Nitrate of Baryta	4
Sulphur	2
	100

This explosive has attained considerable favor in some parts of Europe. In a paper read, by Perry F. Nursey, before the Society of Engineers, London, October, 1871, he speaks of it as containing about 60 per cent of nitro-glycerine, 35 per cent of explosive and absorbent media, and 5 per cent of incombustible matter. Assuming dynamite to contain 75 per cent of nitro-glycerine, Mr. Nursey thereon argues that lithofracteur would give out 20 per cent more power, under conditions of work, than dynamite.

Now, this 20 per cent could only hold good on the manifestly erroneous basis that the strength of the component absorbent explosives is *equal* to that of nitro-glycerine pure. Though the combined salts undoubtedly do add strength to the compound, it certainly is erroneous to assume them as *equal* in strength, cent per cent, to pure nitro-glycerine. Lithofracteur, according to Trauzl, is more sensitive to temperature than dynamite, exploding at 248° F. (120° C.), while the exploding point of dynamite is 356 F. (180° C.), and he further characterizes it as inferior in explosive power to dynamite.

Horseley's Powder

is a compound of chlorate of potash and nutgalls; this, though in itself a powerful blasting powder, has been found to work well with 20 per cent of nitro-glycerine added. Brain's powder is a compound of 40 per cent nitro-glycerine, with a mixture of chlorate and nitrate of potash, wood charcoal, and prepared sawdust.

Dualin.

Dualin was first prepared by Carl Dittmar, a Prussian officer. Its composition, according to Trauzl, is:

	Per cent.
Nitro-glycerine	50
Fine Sawdust	30
Nitrate of Potassa	20
	100

(It is claimed in Dittmar's patent that a substance he calls xylogodine is substituted for ordinary nitro-glycerine in the manufacture of dualin.) As compared with dynamite (No. 1), it is (Trauzl) more sensitive to heat and also to mechanical disturbances, especially when frozen, when it may even be exploded by friction; the gases from explosion, in consequence of the dualin containing an excess of carbon, contain carbonic oxide and other noxious gases (these gases are also evolved, on the explosion of lithofracteur (Trauzl), from the carbon in its composition; they probably also result when carbon is substituted, as it sometimes is, for some of the ingredients in No. 2 dynamite).

The sawdust in dualin has less absorptive power than silicious earth, and retains the

nitro-glycerine comparatively feebly; exudation therefore is liable to occur, unless strong wrappers are used for the cartridges. Trauzl estimates the explosive power of dualin as being 50 per cent less than that of dynamite.

"Rend-rock."

This explosive is another nitro-glycerine compound. It was first made in 1873, and the patent for it was taken out by Beach, of New York. It is described (p. 101) in the patent specifications, and is similar in principle to the No. 2 dynamites.

Colonia Powder,

mentioned by Trauzl, is again another nitro-glycerine compound; it is a mixture of gunpowder with 40 per cent nitro-glycerine. A patent was taken out as early as 1863, by Nobel, for mixing nitro-glycerine with "ordinary powder, gun-cotton, or other analogous bodies." In this patent (dated Paris, September 18th, 1863), it was intended, however, to use the gunpowder as an igniting agent (see p. 68). The art of detonating either nitro-glycerine pure or any of its compounds, by means of fulminating caps, was not known at this date.

Vulcan Powder.

comes in the same general category of compounds similar in principle to No. 2 dynamite; it is said to be composed of from 16½ to 33⅓ per cent of nitro-glycerine mixed with mealed gunpowder. It is hardly necessary to cite any more of the general compounds of nitro-glycerine with explosive salts. They can be almost infinitely multiplied, and are all of the same general type (see p. 86) as their original precursor, No. 2 dynamite. Among others may be noted the following: Hercules, Neptune, Thunderbolt, Vigorite, Potentia, Titan, etc. There have also been a number of patents taken out for combinations, or rather mixtures, of nitro-glycerine with sponge or vegetable fibre: "Porifera Nitroleum," with red lead; "Metalline Nitroleum," with plaster-of-paris; "Selentic Powder," with corn-meal; "Fulgurite," etc. Nitro-cellulose dynamite is a dynamite composed of 75 per cent nitro-glycerine to 25 per cent nitro-cellulose. It has not been received with favor as a blasting compound. There remains only to be considered, among the prominent explosives, Mowbray's "Mica Powder," so called.

Mica Powder.

As to mica powder, it is simply a No. 1 dynamite—*i.e.*, if we understand No. 1 dynamite to be a generic term for all compounds of nitro-glycerine with an inexplosive or inert base. It differs from Nobel's dynamite in the characteristics of its base—that is to say, the difference may be said to be as marked as in the case of dualin, lithofracteur, etc. We have seen that in these the difference in base is claimed to be from the use of salts, carbon, sawdust, etc., in the absorbents. Now, the essential characteristic of Nobel's absorbent—*i.e.*, silicious earth (which is also used in combination with many of the other compounds)—is that the nitro-glycerine is taken up into the fine, porous, microscopic shells composing it by capillary action, and firmly held there. This property of the "kieselguhr," as preventing the tendency to exudation, has been claimed to be the chief value of silicious earth as an absorbent. On the other hand, Mowbray claims that the absorbent used should, in fact, act as a carrier, so to speak, of the nitro-glycerine, but that it should not possess true absorbing powers, arguing that when nitro-glycerine is taken up by a true absorbent, its "quickness" is thereby materially lessened. Nevertheless, Mowbray found and admits (p. 89 of his work on "Trinitro-glycerine") that pure nitro-glycerine will not answer for all cases of blasting, but that for certain uses it is best to use an absorbent; that the question of the true economy of explosives lies in the correct distribution of the explosive force; that while in certain cases, as in deep-heading cuts, the very strongest and quickest agent attainable is the best; that in other cases, as in bottoming and in side-cuts, a better effect is obtained when a less powerful explosive is distributed through a longer line.

Beginning, therefore, with glass blown into fine flakes, and moistened with nitro-glycerine, so that there should be no absorption, but rather cohesion of the mass, he finally settled on finely divided scales of mica as fulfilling the qualities he desired of being elastic and essentially non-absorbent.

It is said that this material has been used with excellent effect at the Hoosac Tunnel and elsewhere. As to the strength of the compound, there can of course be but one opinion, for what is it but a pure nitro-glycerine mixture? As to its comparative value with other explosives, it probably is stronger, pound for pound, than any of those containing a lesser proportion of nitro-glycerine; and, theoretically speaking, it is probably stronger or at least "quicker" than dynamite containing an equal percentage of nitro-glycerine, on the principle that given a certain weight of pure nitro-glycerine, and an equal weight of nitro-glycerine which may then be mixed with an absorbent, the pure article will undoubtedly fire the "quickest," and in the same ratio as the solid matter intermixed leaves the nitro-glycerine freer, it will give the stronger explosive.* We shall, however, see further on that mica-scale will not retain over about 52 per cent of nitro-glycerine, while we know that kieselguhr will hold 75 per cent.

In mica powder, it is claimed by some that, as the mica-scales give an almost infinite number of comparatively clear interstitial air-spaces between the individual scales of the mixture, this condition enables the flame and vibration of the exploder to reach every portion of the cartridge even more quickly than with the same weight of pure nitro-glycerine in liquid form. This is, in fact, a controversy that reminds us of the old one as to whether gunpowder will fire best rammed tight in a bore-hole, or with a hollow space left to supply additional oxygen. Here the question is, will a liquid transmit shock through its body in, say, a cubic mass more quickly than if that mass is laid as an infinitely thin coating over a large surface (for the infinite number of mica-scales may be considered, for discussion, as uniting to form contiguous plane surfaces). If nitro-glycerine were an explosive of the "second order" (see p. 96)—*i.e.*, a slow or rending compound, like gunpowder, in which explosion results from the comparatively appreciably *slow transition of ignition* from atom to atom—then the theory that mica powder was "quicker" than nitro-glycerine would seem passably plausible; but nitro-glycerine is essentially a *detonating* compound, or one of the "first order," in which ignition of the whole mass is effected practically simultaneously, more by shock than by direct ignition, and providing the volume of liquid nitro-glycerine be not larger than the detonating cap, be sufficient to explode, it would seem the safer assumption to say, that the spreading out of this large volume over a large plane surface would tend to remove part of it beyond the direct influence of the detonator—*i.e.*, render it less quick than when fired in pure volume.

But seeking strength was not what drove Nobel to invent dynamite. The safe retention of nitro-glycerine by an absorbent is what is desired, and the undoubted inference is open that the "freer" the absorbent will leave the nitro-glycerine, the more liable will it be to exudation (as we have seen in Trauzl's opinion of dualin), for though nitro-glycerine at 50° to 60° F. (10° to 15° C.) is a thick liquid, easily retained, yet at 90° to 100° F. (32° to 37° C.) it becomes quite limpid; and in the direct ratio in which it is left "free" will it approach the objections to the use of pure nitro-glycerine which the employment of an absorbent is designed to avoid. It is, on the other hand, claimed that the elastic, resilient properties of the mica-scales cushion the nitro-glycerine effectually from accident by concussion, and that the large superficial area presented by the scales gives so much adhesion surface as to retain the liquid.

This power of retention, however, must have some limit. Nobel found positively that 75 per cent was the highest proportion of nitro-glycerine that infusorial earth would hold

* This has been disputed; see footnote page 98.

securely. It cannot be physically contended that the plane surfaces of mica-scales have the capillary attraction that infusorial earth has; indeed, it is specifically claimed by Mowbray that mica-scales were chosen by him on account of their non-absorbent quality. Practically, it is found that from 50 to 52½ per cent of nitro-glycerine, according to the temperature, is the highest proportion that can be retained by mica-scale even with a paper cartridge.

The practical final inference would seem to be that in cases where the use of pure nitro-glycerine is not desired, and yet a high dynamite (75 per cent nitro-glycerine) needed, then that the absorbent chosen should be such a substance, as infusorial earth is, as will effectually retain this high percentage from exudation.

Again, as we have seen that a low percentage of nitro-glycerine mixed with infusorial earth alone is essentially non-explosive without the admixture of other less absorptive substances in the dope, it would here seem that, with a low percentage of nitro-glycerine, mica-scale, or some equivalent substance, may be preferred as an absorbent, where an *inert base* is desired, for experience has effectually shown that a low percentage of nitro-glycerine mixed with mica-scale alone is explosive. Mica powder would have the equal advantage with dynamite, that in its explosion no gases are developed but the innocuous ones of nitro-glycerine proper. (The above full description of mica powder is given as it raises interesting questions in the manufacture of explosive compounds. With regard to its special features, however, it is interesting to note that the courts have decided it to be a dynamite.)

Gum Dynamite, or Explosive Gelatine.*

Gum dynamite, discovered by Nobel, is a true chemical compound of nitro-glycerine and nitro-cellulose. By varying the percentage of gun-cotton or other nitro-cellulose used, the resulting product will vary from a gum of horny aspect to a syrup.

The gum state is most preferred, and is rendered less sensitive by adding camphor or nitro-benzine. The mixture of 7 or 8 per cent gun-cotton and 93 or 92 per cent nitro-glycerine is greatly superior to nitro-glycerine or simple dynamite. If camphor be used, it is liable to evaporate, and let the gum, to a certain extent, re-acquire its sensitiveness. But there always remains enough camphor to render the gum less sensitive than simple dynamite. Gum dynamite is amber-yellow and transparent, having a density of 1·6. It may be cut like jujube paste, and submitted to a pressure of 1,000 kilogrammes without exudation. In the open air it burns quietly, crackling slightly. Exploding, it makes a clearer and sharper report and less smoke than does nitro-glycerine.

It requires slightly different tamping, explosion, firing, handling, transportation, etc., as it is affected in some cases where ordinary dynamite is not.

Water tamping, instead of lessening its force, is said to greatly increase it, and produces no change in the composition, but carriage under water decreases danger in transportation. After being immersed in water it shows no evidences of exudation.

Firing.

The old regulation exploders for frozen dynamite will not cause perfect explosion of explosive gelatine. A special powerful cartridge, made of 25 per cent cotton powder and 75 per cent nitro-glycerine, yields superior results. While ordinary dynamite explodes under a shock of 1 kilogrammeter,† 2 to 5 kilogrammeters are necessary to detonate gum dynamite.

Handling.

It has been customary to handle nitro-glycerine and dynamite in a frozen state. Unfortunately the effect of cold on gum dynamite, instead of decreasing its liability to explosion, is to render it more sensitive to shock. It freezes at 6° C. Freezing does not, however, lessen the effect of explosion.

* See Engineering and Mining Jour., June 10, 1832, for tests of Gum Dynamite, by Gen'l Abbot, U.S.A.

† One kilogrammeter = 7.233 foot-pounds.

In thawing, a sand bath is usually employed, the cartridges being placed in zinc vessels and care taken not to undo the cartridges. The zinc pans should be washed, from time to time, with alcohol or ether, to prevent accidents when re-soldering their seams.

Explosive gelatine has about twice the rending force of dynamite. In ordinary rock the gum is about one-half stronger than dynamite, but in very hard rock, double. It has been tested in lead blocks with dynamite, and has yielded 50 per cent greater cavity volume than simple dynamite.

The above description of gum dynamite is translated and condensed from an exhaustive article on the subject by M. Moreau.* In his article M. Moreau gives the following table of the comparative results attained by black powder, dynamite No. 1, and gum dynamite, at the St. Gothard Tunnel.

	BLACK POWDER.	DYNAMITE NO. 1.	GUM DYNAMITE.
Number of holes	80	24	12 to 16
Depth of holes, meters	0m.70 to 0m.90	1m.20 to 1m.60	1m.20 to 1m.50
Diameter of holes	0m.040 to 0m.070	0m.025	0m.020
Weight of charge	34 kilo.	16 to 20 kilo.	10 to 14 kilo.

Although slightly dearer than dynamite, it does one-third to one-half more work. Its gases of explosion are less deleterious to health than those from dynamite or gun-cotton.

Picrates.

The picrates are salts of picric acid, $C_6H_3(NO_2)_3O$ or $C_6H_3N_3O_7$. A large number of them are known, but the potassium and ammonium salts are the only ones that have been much used in explosive preparations. Designolles' blasting powder is a mixture of potassium nitrate (saltpetre) and potassium picrate. Abel has applied a mixture of ammonium picrate and saltpetre as a powder for bombshells. These compounds are rather applicable, if at all, to military than mining purposes, and do not concern the question of tunneling. They have been used for charging explosive bullets.

Norrbin and Ohlsson have, however, patented a blasting powder composed of the nitrate or nitrite of ammonia, mixed intimately with a fulminate, which may be the "picrate of potash, nitro-mannite, or nitro-glycerine." It has been made in the proportion:

	BY WEIGHT.
Nitrate of Ammonia	30 parts.
Coal	6 to 8 "
Nitro-glycerine	10 " 20 "

The main application of the picrate of potash as an explosive agent is rather as a fulminate than for charging proper.

Fulminates.

The fulminates are salts of fulminic acid ($C_2H_2N_2O_2$). The mercury salt is the only one of practical value.† All of them are easily exploded, and some are excessively sensitive. Their explosions are very sharp, from the extreme rapidity of their decomposition; but from the small amount of gas given off, the force exercised is not very great. Fulminating mercury ($C_2H_gN_2O_2$) explodes violently when forcibly struck, when heated to 367° F. (186° C.), when touched with strong sulphuric acid or nitric acid by sparks from flint and steel, or on passing the electric spark. When wet, it is inexplosive. Its explosive force is not much greater than that of gunpowder, but it is much more sudden in its action.

The readiness with which it may be fired makes it an excellent means of causing the explosion of other substances, being essentially a detonating powder. It is, therefore, as we

* *Mémoires de la Société des Ingenieurs Civils*, December, 1880.

† See, for an exhaustive study of the explosive properties of fulminate of mercury, an article by Berthelot and Vielle, *Annales de Chimie et de Physique*, 1880, p. 564.

have seen, a requisite for exploding gun-cotton, nitro-glycerine and its compounds, etc., and it is a substance of especial and great interest to the tunnelman, as it is wholly through its agency that the great force of these high explosives is fully brought out. Properly made, fulminate fuses or exploders are perfectly safe; but unless care is taken in the manufacture, they may be dangerous.

They are all of the same general type, and are substantially prepared by placing a small quantity of sensitive powder or priming in the cap, and in it the extremities of the wires are inserted. (At Hoosac, Mowbray * used for sensitive powder the sulphide and phosphide of copper with chlorate of potash.) (See as to electrical fuses, *post* p. 111.)

From 15 to 25 grains of fulminating powder were added in the early types; the spark, on passing, ignites the sensitive powder, which again fires the fulminate, and the detonation of the latter fires the charge. (These heavy fulminate charges in caps have, however, been very much lessened of late years. The commercial caps in general use may be assumed to generally contain not over from 6 to 8 grains of fulminate, and often less.)

When improperly made, fulminating caps are, of course, a fruitful source of danger and loss. The cost of exploders is but a very small item when compared with the cost of the blasting material and the expenses attending its use. Contractors and others using them on a large scale often lose heavily by their own mistaken economy or carelessness in using inferior makes. A single accident that would not have occurred if good exploders had been used, will often cost the operator much more than all the exploders he uses in a year.

Many of the cases, however, in which unexpected explosions of caps occur which are set down to defects in the exploders, are clearly attributable, on investigation, to ignorant handling.

Others, however, occur which seem unaccountable, except through decomposition of the fulminate. In the author's own experience, such a case occurred in 1874 at the Musconetcong Tunnel. The contractor, Mr. Charles McFadden, used the Hamburg caps supplied by the Atlantic Giant Powder Company. Those for the East Heading were kept on the second floor of a store-house, with other miscellaneous goods. One night, from some cause never determined, there was a sudden explosion of a number of them, the box at the time containing several thousand. Most probably the mischief came from one single original explosion which fired the adjoining caps. A man was sleeping in the room within fifteen feet of the box. The sides of the house and the roof were torn off, and the floor crushed in, but the man escaped entirely unhurt. It being winter, he was well wrapped up in blankets, so the flying cartridges failed to harm him, though his watch hanging at the head of his bed had the works completely blown out.

Mowbray says † with regard to exploders, that the important points to secure in their manufacture are "uniformity of composition; that they shall not offer too great resistance to the spark; that they shall not be so sensitive as to explode either from the ambient electricity of the atmosphere, or from the electricity pervading a tunnel, caused by the friction of the air from the compressors when it escapes through the vulcanized rubber of the connecting pipe."

As to the practical danger of disregarding this source of electrical action, Mowbray further says: "This source of electricity, I believe, caused an accident March, 1873, at the Hoosac Tunnel, killing a man; and it was followed by another similar in every respect a fortnight afterward; for as the blaster charging the holes on the last occasion, observed: 'The moment I touched the bare wire (after the insulated portion had passed through my hand), premature explosion ensued.' It had been the custom, after withdrawing the drilling-machines, to allow a pretty free discharge of compressed air for ventilation; and, assuming a man in his rubber boots to be an insulated jar, the hands, face, etc., would serve as

* On Trinitro-glycerine, p. 74.　　† Ib., p. 74.

collecting points, while the electricity developed by the moist vesicles of the cold, expanding air rushing through a pipe from a reservoir charged up to fifty or sixty pounds per inch, would closely resemble the hydro-electric machine, and develop considerable electricity. The blaster, not aware that he is a walking charge of electricity, proceeds to his work, inserting cartridge after cartridge of nitro-glycerine, until he comes to the last, which is armed with the electric fuse. The moment his hand touches one of the naked wires, the current passes through the priming, and explosion follows.

"Let a blaster, before he handles these wires, invariably grasp some metal in moistened contact with the earth, or place both hands against the moist walls of the tunnel. Before taking the leading wires to the electric fuse wires, let the bare ends of the leading and return wires be brought first into contact with themselves, and then into contact with the moist surface of the tunnel, or some metal in good connection with the ground, and, before inserting the armed cartridge, let him unite both of the uncovered naked wires, and touch them to a metal surface having good ground connection. Above all, do not ventilate by allowing a free blast of air through a rubber connecting pipe, until after the electric connections have been made and the blast fired."

The author personally remembers an instance where a blaster was walking into the tunnel with a number of caps slung over his shoulder, the caps hanging down his back, and the ends of the wires being in his hands. Suddenly, several of them exploded, damaging his shirt considerably, but not hurting the man seriously.

During the spring of 1877, Mr. Adolphe Sutro instituted a series of experiments at the Sutro Tunnel, to test whether the electric exploders used there were capable of being readily fired by electricity communicated from the human body. Repeated trials tended to prove the great danger that may be incurred by carelessly handling them *after* the ends of the wires have been stripped of their gutta-percha covering. It was found that a man moving briskly across a carpeted floor, rubbing his feet on the carpet in doing so, in fact sliding, became so charged that, under favorable circumstances, caps were repeatedly fired by sparks from the end of the finger. This emphasizes the fact that the ends of the wires should not be stripped until the caps are really required for use. That is to say, they should not be stripped, for instance, several days ahead, and a body of such unprotected caps left lying around, as is often done.

Storage of Explosive Compounds.

Blasting materials should be carefully stored in magazines properly constructed, and placed at a safe distance from houses or shanties adjoining the work.

Care should especially be taken in the storage of nitro-glycerine and its compounds, that the exploding caps and the explosive be kept in different places of deposit.

Gunpowder and the glycerine compounds should never be kept together. The construction and position of magazines for the glycerine compounds must depend greatly upon the climate. Fig. 15 shows a plan of magazine that has been used. In warm latitudes, cool storing-places are necessary; while in cool countries, it is advisable to select only such places as will insure a temperature of from 50° to 60° F. (10° to 15½° C.) being maintained. Cellars or sheds covered with earth prove the best in all climates. Particular cautions with regard to the storage of gunpowder are hardly necessary, its characteristics, its ready liability to ignition, and consequent explosion, being familiar to all. Fig. 16 may be taken as a design for a magazine.*

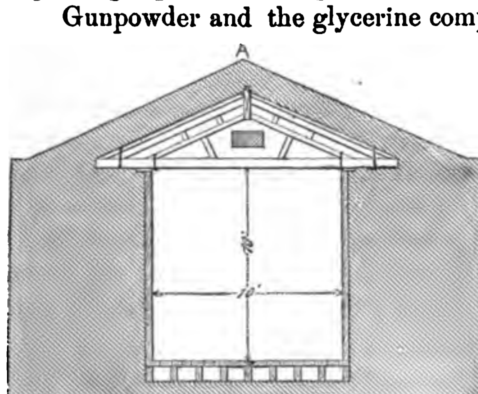


Fig. 15

* From Schoen, "Der Tunnelbau," p. 73.

With the glycerine compounds, however, the fact is indubitably established that, when in good condition, they are absolutely non-explosive under ordinary circumstances, unless fired by percussion and heat combined, or under pressure. These compounds are only rendered liable to explosion by the presence of the caps or exploders, therefore too much care cannot be used in the storage of the two. Where a large quantity of an explosive is used on a piece of work taking some time to complete, the bulk of the explosive is usually kept in a magazine at a distance from the works, and the cartridges made up in a separate "dry-house" when needed. Here also watch should be kept that care is used in the preparation of the cartridges, as the quantity of explosive in the dry-house will often necessarily be several hundred pounds, where work is lively and the charges heavy. The carelessness shown by workmen is often absolutely inconceivable. It can safely be assumed that, in nine cases out of ten, accidents result directly from this cause.

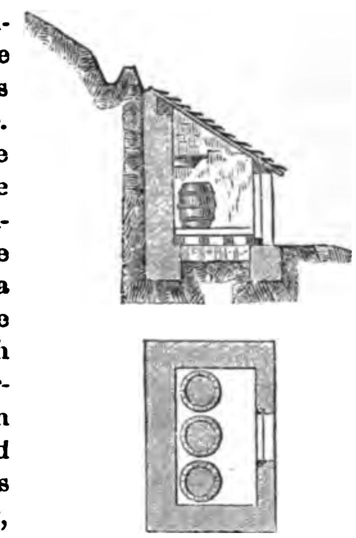


FIG. 16.

The following accident occurred, in the author's experience, on a piece of work where dynamite was the explosive used and preferred. As it was in winter, a stove was kept in the dry-house to thaw out the powder which had frozen in the magazine. One day, there being three men in the room, one of them, becoming impatient, took two cartridges and held them to the fire to thaw more quickly. He heedlessly held them so close, that one of them became ignited, when, instead of throwing it out of doors, or into the fire to burn, in his confusion he dropped it into a box of cartridges *ready capped for a blast.* The men had just time to get some 50 or more feet away, when the 200 pounds of dynamite in the house blew up. This dry-house was situated about 200 feet off the line of the tunnel, and about 500 feet from the portal, yet the explosion put out the lights of the gang working at the bottom, some 1000 or more feet in. It also shattered the glass in the neighboring shanties, the nearest being about 500 feet off; no one was hurt. This accident was one of the strongest arguments in favor of the safety of dynamite that could be advanced. Suppose a man were to drop a light into a box of gunpowder, is it likely it would give him time to get out of danger, and then only blow up because the fire reached some caps designed to explode it?

With regard to the storage of nitro-glycerine and the construction of the dry-house, in which the portion to be presently used is prepared for blasting, the following notes are from the experience of Mr. E. P. North. As to the magazine, Mr. North advises only a shed just strong enough to keep intruders out, on the principle that the less possibility of compression, the better. Both nitro-glycerine and dynamite (in the temperate zone) will remain frozen in such a magazine for probably one third of the year. As noted, p. 72, it is most safely thawed out in a dry-house having a room heated by steam, conveyed in gas-pipes so arranged that the *outlet to the pipes can never be entirely closed.* This room should have shelves of sufficient capacity to hold about three days' consumption, as it will take about two days to thaw out a loose pile of $1\frac{5}{8}''$ cartridges at a temperature of from 60° F. to 70° F. When using dynamite for subaqueous blasting, allowing one hour to load a series of holes, Mr. North usually warmed up the room to about 90° F. for about two to three hours before commencing to load.*

With regard to the use of water in storing nitro-glycerine, Mr. North wrote the author (August, 1877): "I have lately kept nitro-glycerine covered with water containing caustic

* Where the stock on hand is not too large, it is probably better in winter to keep dynamite in a warm dry room on shelves or slats; when once thawed out, it will remain so. Moreau suggests that at works where a large stock is kept on hand, a good plan is to cover the floor of the magazine with fermenting stable manure. He states this was done at the St. Gothard Tunnel, and that the heat of the manure is sufficient, except in very cold weather, when it may be supplemented by burying in the manure metal vessels containing hot water.

soda or carbonate of soda, stirring it from time to time with a stick, and testing it with litmus-paper, believing that when neutral or alkaline there is no danger of spontaneous explosion."

Mr. Chas. L. Kalmbach (see Patent No. 153,086, p. 102) who is an expert with nitro-glycerine, advises storing it in open earthenware crocks with perpendicular or flaring sides, and covered with only a thin film of water. As to dynamite No. 1, there is no occasion to use water in preserving it; the water would rather do harm; it keeps well enough in a magazine, as described above. With the No. 2 dynamites, water tends to dissolve the salts and weaken them.*

Discussion of the Different Explosive Reagents.

And now with regard to the comparative characteristics of the different explosives, it would be rash to lay down any empirical rules as to the one being better or worse than the other.

The question must vary with the character of the material used and with the position in the material (whether heading or bottom) in which the explosive is to be applied, and we can, perhaps, consider the question better after reviewing the principles of blasting in the succeeding chapter. There are, however, some comparative tables of the intrinsic properties of the different compounds (not of results of their application), which may be of interest here.

We have seen, in the discussion of the three principal explosive compounds, what their calculated power is. It may now be well to present these figures in direct contrast: †

TABLE 10.

	POWDER.	NITRO-GLYCERINE.	GUN-COTTON.
Mixture of gases in cubic centimetres at 32° F. (0° C.) produced by 1 gramme of the explosive	200	2,000	1,200
Temperature of these gases in degrees centigrade	3,300	5,200	4,500
Theoretical maximum pressure in atmospheres (1 kilogramme to 1 square centimetre)	4,300	26,000	15,300
Theoretical maximum power per kilogramme of explosion in kilogrammetres	42,000	400,000	200,000
Theoretical maximum power per kilogramme of explosion in foot-pounds	303,786	2,893,200	1,446,600

Now, from this, it would appear that the theoretical maximum pressure of nitro-glycerine is six times, but the theoretical maximum power ten times that of gunpowder. Berthelot has calculated the quantity of heat generated in the explosive reaction of different bodies, and the volume of gas formed—the product of these numbers giving a term of comparison between the pressure that, as he conceives, "accords in general with experience."

TABLE 11.

EXPLOSIVE SUBSTANCES.	Quantity of Heat evolved per kilo.	Volume of Gas formed.	Product of the two preceding Numbers.
	cal.	m. c.	
Blasting Powder	510,000	0·173	88,000
Chloride of Nitrogen	316,000	0·370	117,000
Artillery Powder	608,000	0·225	137,000
Sporting Powder	641,000	0·216	139,000
Nitrate of Soda Powder	764,000	0·248	190,000
Picrate of Potash and Saltpetre	852,000	0·337	286,000
Chlorate of Potash Powder	972,000	0·318	309,000
Picrate of Potash	578,000	0·585	337,000
Picric Acid and Saltpetre	923,000	0·408	376,000
Gun-cotton	590,000	0·801	472,000
Picrate of Potash and Chlorate of Potash	1,422,000	0·337	478,000
Nitrated Gun-cotton	989,000	0·484	480,000
Picric Acid	687,000	0·780	536,000
Picric Acid and Chlorate of Potash	1,424,000	0·408	582,000
Chlorated Gun-cotton	1,420,000	0·484	680,000
Nitro-glycerine	1,320,000	0·710	939,000

* On this point see p. 118.

† These figures are given both by Trauzl and Schoen.

By this table, it would appear that, theoretically, sporting powder, though giving out more heat than either blasting or cannon powder, is still not much stronger. Again, blasting powder is one of the lowest of explosives. The ratio of gun-cotton to blasting powder is, theoretically, over 5 to 1, and that of pure nitro-glycerine over 10 to 1. These proportions, however, are considered practically as too high. Sarrau,* in some more recent experiments, has taken the ground that the force of any explosive substance is nearly proportional to the product of the heat of combustion, by the weight of the permanent gas produced by the combustion, and has, from experiments, prepared the following table:

Name of Substance.	Relative Force.
Saltpetre Powder	1
Chloride of Nitrogen	1·08
Mixture of 55 parts Picrate of Potash and 45 parts Saltpetre	1·49
Mixture of equal weights of Picrate and Chlorate of Potash	1·82
Picrate of Potash	1·98
Gun-cotton	3·06
Nitro-glycerine	4·55

This again would appear practically to be too low a ratio to express, for instance, the relative force of nitro-glycerine and saltpetre powder; the reason is that, under the circumstances in which the higher explosives are now used, their full strength is more completely brought out than that of powder.

This has well been shown in the researches of Roux and Sarrau on detonation. To their joint researches is chiefly due the light that has been thrown on the possibility of producing two kinds of explosion in the same substances, and they distinguish them as being of the *first* or of the *second* order. An explosion of the first order occurs when the explosive is fired by the application of heat and percussion; an explosion of the second order occurs when the explosive is fired simply by the application of heat, as in applying flame. An explosion of the first order being produced in an explosive by the detonation of a substance having primarily that quality (as fulminate of mercury) may itself be called a "detonation," as contradistinguished from an explosion of the second order, which is what has always been known by the simple term "explosion."

As to the detonating powders proper, Sprengel remarks: † "It is to be regretted that no exact method exists for comparing the force of detonating explosives." How a detonating substance directly affects a sympathetic detonation in another explosive, not primarily detonable, is not yet determined.

Detonation may be defined to be the instantaneous explosion of the whole mass of a body. Thus, when gunpowder is fired in the usual manner, true combustion takes place, which goes on with comparative slowness from the surfaces of the grains toward their interiors. On the other hand, when nitro-glycerine is fired by means of fulminating mercury, the whole mass explodes simultaneously or nearly so. Ordinary gunpowder can be detonated if fired with a small amount of nitro-glycerine which primarily is detonated by a fulminate.

The following table ‡ shows the results of Roux's and Sarrau's experiments on the relative force developed by the simple explosion and detonation of the three prominent explosives:

* "Recherches Théoretiques sur les Effets de la Poudre et des Substances Explosives."
† Journal Chemical Society, I., p. 802.
‡ André on Coal-Mining, p. 207.

TABLE 12.

RELATIVE STRENGTH OF EXPLOSIVE COMPOUNDS.

SUBSTANCE EXPLODED.	Simple Explosion.	Detonation.	Relative weight of Gases.	Heat disengaged by 1 lb.	
				Simple Explosion.	Detonation.
Gunpowder	1·00	4·34	0·414	1316	1318
Gun-cotton	3·00	6·46	0·850	1902	1909
Nitro-glycerine	4·80	10·13	0·800	3097	3200

Now, this table shows most emphatically the enormous increase of force gained by detonation over explosions; for ordinary gunpowder is seen to be raised at once to over four times its explosive strength. It must further be remembered that in practice, gun-cotton and nitro-glycerine are detonated in blasting, while black powder is not. Practically, nitro-glycerine can therefore (Hill) be said to be about eight times as powerful as black powder, dynamite (75 per cent nitro-glycerine) six times, and gun-cotton from four to six.

Curtis and Harvey have recently produced in England a variety of gunpowder (known as E. S. M.), which, owing to its possessing the quality of quicker ignition, has been found (according to André) to be susceptible of direct detonation, and has, on detonation, developed an enormous increase of force; greater than the relative amount found for gunpowder in Roux and Sarrau's experiments, and, in fact, little if at all inferior to dynamite, with a percentage of 75 parts of nitro-glycerine. (This would in a measure explain the force developed by the dope of No. 2 dynamite, if the latter is considered to be detonated.) Now, this discussion leads directly to the conclusion so ably put by André, that the various explosive compounds, according to their work in blasting, can clearly be divided into the two classes of,

1. Slow or rending compounds.
2. Quick or shattering compounds.

A slow or rending compound is therefore distinctively one in which the transformation of the substance into gaseous form is slow, and where the explosive force is exerted by degrees as the gases are developed; and these compounds are the ones in which the greatest effect produced is not invariably at the exact point at which the explosive is located—*i. e*, the gas being slowly evolved, will tend to concentrate its strength and act in the line of least resistance, and the pressure upon the containing body can in no part be greater than that which is exerted on the part which yields—*i. e.*, it can never be greater than the resistance of the least resistant part. This class of explosives is, of course, especially applicable in quarries, etc., where the material is required to be blasted in certain shape or in large blocks. Gunpowder is its prominent type.

A quick or shattering compound is, on the other hand, one where the transformation of the substance into gas occurs practically instantaneously, and the full force of the enlarged volume is at once exerted in all directions and upon every part of the containing body, because motion requires time, and as no time is allowed for the less resistant part to yield, by moving away before the pressure of the fluid, it follows that the whole force of the latter must be exerted upon all alike; the rock is therefore not only blown out in fragments to the full depth of the hole, but is violently strained and shattered in the immediate vicinity of the hole, even where the resistance is greatest; so we see that these shattering explosives are of course of especial value in tight headings driven through hard rocks. Of this class, nitro-glycerine is the distinctive type.

Between gunpowder and nitro-glycerine as extremes, the other explosives in use range according to their strength; and we must remember, in studying their practical application to blasting, that, in choosing the best explosive for a particular piece of work, and in different parts of the same work, many circumstances must be taken into consideration: whether the material to be blasted is homogeneous in its character, whether it be a hard, soft, or loose rock, and whether time (as in most railroad-tunnels) is an essential element in the problem. In the same piece of work different explosives can generally be used to advantage, in the different workings, with economy of both time and money; as in a tunnel, the heading often requires a quick, and the bottom a lifting force. For this reason, it will not do to assume that one explosive is practically a better one than another, in the ratio in which it may be said to exceed it in power. No general comparison can be made or empirical rule laid down, but good judgment in this as in other engineering problems must be exercised.* (See page 133.)

* *Comparative Value of Mining Explosives.*—London *Iron* of Oct. 29, 1880, says that the Joint Committee of the Royal Cornwall Polytechnic Society, the Miners' Association of Cornwall and Devon, and the Mining Institute of Cornwall, appointed to inquire into the nature, economy, efficiency, and safety of the various explosives in use or proposed for use in the mines of Cornwall and Devon, issued a report showing:

1. That they dealt with gunpowder of five different grades.
2. Espir's explosive powder, a mixture of nitrate of soda 60, sulphur 14, sawdust 26 per cent.
3. Gun-cotton.
4. Tonite, said to be gun-cotton combined with nitrate of baryta.
5. Titanite.
6. Dynamite, two varieties, one nitro-glycerine 75 and Kieselguhr 25 per cent, and the other less nitro-glycerine and some charcoal and nitrates.
7. Blasting gelatine, collodion cotton 7 to 10 parts, 90 to 93 per cent of pure nitro-glycerine, nearly all the cotton being soluble in alcohol.
8. Liverpool cotton-powder, a mixture of gun-cotton and nitrate of potash.

The first trials were in the open quarry, a number of holes having been drilled, to give, as far as possible, similar conditions. Each competitor had three holes, and the value of the work done was estimated from the cost of the powder as a standard. Seven different kinds of explosives were used, including three kinds of powder (common, compressed, and special strong). The result showed that assuming the work done to be approximately proportionate to the depth of the holes, common powder was the cheapest—¾ penny per foot of hole, and dynamite the most costly—3½ pence per foot. The second series of experiments consisted in driving levels not less than 7 feet high and 4½ feet wide. Six kinds of explosives were tried—dynamite, Espir's, Liverpool cotton-powder, compressed and common powders, and tonite. Here the compressed powder took the lead, the total cost per foot run of level, being 5 shillings 1¼ pence (1 shilling 1 penny for materials, and 4 shillings ¼ penny for labor). The dynamite came out fourth, and the tonite was the most expensive. In reply to a number of questions, dynamite was declared to be the best in wet grounds, and the majority declared for the same explosive under most all circumstances, except for very dry places, where powder was preferred. Nearly all agreed the fumes from dynamite were the most dangerous, and a considerable weight of opinion prevailed that powder was less dangerous to deal with than any other explosive. They said that there was always danger in using dynamite in fissured ground, as unburnt portions of the charge were blown into the fissures and exploded unexpectedly afterwards by the workmen.

Recent experiments by General Henry L. Abbot, U. S. Engineers, on the comparative force of explosives when fired under water, has shown that nitro-glycerine, fired under water, is less effective than dynamite No. 1. This he attributes to the circumstance that as the resistance of water is of a slightly yielding character, a certain time is required to overcome this resistance, so that the more powerful explosive, acting too suddenly, is less effective. This explanation, however, appears not to agree with the conclusions reached by the Austrian Technical Committee, who are said to have demonstrated that a dynamite containing 74 per cent. of nitro-glycerine, when fired with open charges, on the top of a rock, is more powerful than pure nitro-glycerine. (See Engineering and Mining Journal for July 29, 1882, vol. 34, p. 55.) General Abbot's researches are of great value, and are given in No. 23 of the papers of the Corps of Engineers, U. S. A., 1881. The result of his tests with various explosives showed that their relative intensity of action, *horizontally*, when fired *under water*, was as follows, dynamite No. I, being 100:

Explosive gelatine	117	Dynamite, No. 2	83	Vulcan powder, No. 1	78
Dualin	111	Mica powder, No. 1	83	Electric powder, No. 1	69
Hercules powder, No. 1	106	Hercules powder, No. 2	83	Designolle powder	68
Dynamite, No. 1	100	Vulcan powder, No. 2	82	Electric powder, No. 2	62
Rend-rock	94	Nitro-glycerine	81	Mica powder, No. 2	62
Gun-cotton	87	Brugere powder	81		

(See Engineering and Mining Journal, New York, June 17, 1882, vol. 33, p. 312, for an interesting abstract of General Abbot's conclusions.)

TABLE 13.

LIST OF PATENTS FOR EXPLOSIVE COMPOUNDS ISSUED IN THE UNITED STATES SINCE THE INTRODUCTION OF HIGH EXPLOSIVES.

(The following notes are direct condensations of the patent specifications. The author is not to be held responsible for or as indorsing any opinions, claims, etc., advanced, except those in the foot-notes.)

ORIGINAL PATENTS.		REISSUES.		NAME OF PATENTEE.	NAME AND DESCRIPTION OF EXPLOSIVE.
DATE.	NUMBER.	DATE.	NUMBER.		
1865.					
October 24......	50,617	....	....	Alfred Nobel.	Nitro-glycerine as a substitute for gunpowder.
		1869.			
....	....	April 13........	3,377	U. S. Blasting Oil Co.	Exploding nitro-glycerine
....	....	" 13...	3,378	" " " "	" "
....	....	" 13........	3,379	" " " "	Manufacturing nitro-glycerine.
....	....	" 13........	3,380	" " " "	Use of nitro-glycerine.
		1872.			
....	....	March 19.......	4,815	" " " "	Methods of exploding nitro-glycerine.
....	....	" 19.......	4,816	" " " "	Other methods of exploding nitro-glycerine (exploders, etc.).
....	....	" 19.......	4,817	" " " "	Manufacture of nitro-glycerine.
....	....	" 19.......	4,818	" " " "	Patent especially claims combinations of nitro-glycerine with gunpowder and gun-cotton.
....	....	" 19.	4,819	" " " "	Mixture of nitro-glycerine and rocket powder.
		1873.			
....	....	October 21....	5,620	Atlantic Giant Powder Co.	Methods of exploding nitro-glycerine (exploders, etc.).
....	....	" 21.....	5,621	" " " "	Other methods of exploding nitro-glycerine.
		1874.			
....	....	March 17.......	5,798	" " " "	Exploding nitro-glycerine (process).
....	....	" 17.... ..	5,800	" " " "	" " (exploders, etc.).
1866.					
July 24.........	56,620	....	....	Tal. P. Shaffner.	Packing nitro-glycerine.
August 14......	57,175	....	....	Alfred Nobel.	Nitrine.
		1867.			
....	....	April 2.........	2,537	U. S. Blasting Oil Co.	"
....	....	" 2.........	2,538	" " " "	Manufacture of nitrine.
		1869.			
....	....	April 13........	3,381	" " " "	" " "
....	....	" 13........	3,381	" " " "	" " "
December 18 ..	60,567	....	....	Tal. P. Shaffner.	Charging bombshells with nitro-glycerine.
" 18 ..	60,569	....	....	" "	Electric fuses.
" 18 ..	60,572	....	....	" "	Combination of blasts to be discharged simultaneously by electricity, in such manner as to effect a conjunctive force of the respective charges, thereby increasing the disruption of matter beyond what can be obtained by separately discharging the said blasts.*
" 18 ..	60,573	....	....	" "	Mixing nitro-glycerine with sand in the bore-hole, so as to distribute the force throughout the hole. Also for placing charge of nitro-glycerine at bottom of hole with tamping charge near top, space existing between the blasting and tamping charges. Also for column of water introduced into this space.
		1869.			
....	....	April 13.... ...	3,374	" "	Mixing nitro-glycerine with sand.
		1876.			
....	....	January 11......	6,854	" "	" " " "
		1869.			
....	....	April 13........	3,375	" "	Tamping charge and bottom charge with vacant space. Also vacant space filled by water-column.

* A patent for this identical system of blasting was issued to Moses Shaw, of New York, June 3d, 1830. See Journal of the Franklin Institute, Philadelphia, October, 1830; also Silliman's Journal, vol. xvi., p. 372.

ORIGINAL PATENTS.		REISSUES.		NAME OF PATENTEE.	NAME AND DESCRIPTION OF EXPLOSIVE.
DATE.	NUMBER.	DATE.	NUMBER.		
1868. April 7	76,499			George M. Mowbray.	Manufacture of nitro-glycerine. Current of compressed air forced through nitro-glycerine during manufacture, enables operator to use glass vessels, converts hyponitrous acid (deutoxide of azote) contained in the mixed acids into nitric acid, and carries off remainder into atmosphere; acts mechanically in mixing ingredients.
May 26	78,317			Alfred Nobel (assignor to Julius Bandmann).	Dynamite.
		1873. October 21	5,619	Giant Powder Co.	"
		1874. March 17	5,799	" " "	"
June 23	79,268			H. Julius Smith.	Electric fuse.
September 8	81,894			Joseph Hafenegger.	Various chlorate of potash powders. Also a "self-igniting" liquid, consisting of one or two, more or less, parts of phosphorus dissolved in two parts of bisulphide of carbon.
1869. January 19	85,906			Stephen Chester and Otto Burstenbender.	Process for manufacturing nitro-glycerine. Use of carbonic acid gas in the production of nitro-glycerine and "explosive fluids or mixtures;" mixtures cooled by ebullition of compressed carbonic acid gas and ingredients mixed under an atmosphere of carbonic acid gas.*
February 9	86,701			Tal. P. Shaffner.	Packing or storing nitro-glycerine that has been treated with soda or alkali to remove excess of acid, in cold water; presence of water claimed to remove excess of either alkali or acid.
March 13	88,171			William H. Jackson (assignor to Upton *et al.*)	Oriental powder. Combination of gunpowder or other explosive compound with vegetable fibre. Tan-bark, sawdust, or other vegetable fibre, saturated with solution of a nitre or chlorine salt, is dried and mixed with gunpowder, etc. Bark which has been used by the tanner preferred, as operation of tanning has drawn from it salts, which might prevent it burning freely.
July 27	93,113			George M. Mowbray.	Electric fuses.
August 17	93,752			Tal. P. Shaffner.	Selenitic powder. Mixture of nitro-glycerine with plaster-of-paris.
" 17	93,753			" "	Porifora powder. Nitro-glycerine with sponge or vegetable fibre, and also mixture of the above compound with plaster-of-paris.
" 17	93,754			" "	Nitro-glycerine with pulverized red lead. Plaster-of-paris may also be added.
" 17	93,755			" "	Fuse made by applying to the lower end of an ordinary blasting fuse a jacket or covering, made of some rapid explosive substance, this substance being intended, by its ignition, to spread the fire throughout the whole charge of gunpowder more quickly.
" 17	93,756			" "	Process for manufacturing nitro-glycerine.
" 17	93,757			" "	Method of blasting by the interposition of non or partial explosive materials through the bulk of a charge of explosive compound, in order to spread the action of the gases evolved by the explosive over a greater cubic space.
September 14	94,847			" "	Application of intestine, membranaceous, or cutaneous matter, for sacks or bags to be used as artillery or blasting cartridges.
November 2	96,465			George M. Mowbray.	Compound styled "Mowbray's Safety Priming for Electric Fuses," composed of, in parts, phosphorus 5, sulphur 15, silver 100, mercury 25, chlorate of potash 30. Claimed not to be so dangerous to handle as fulminate of mercury *per se*, or when mixed with precipitated copper, and also claimed to be more sensitive than the latter.
November 23	97,241			H. Julius Smith.	Electric fuse.
December 28	98,382			John Horscley.	Incorporation of nitro-glycerine with either a mixture of powdered Aleppo or other foreign gall-nuts, and chlorate of potash; or with a mixture of powdered galls, charcoal, and chlorate of potash; or with a mixture of powdered galls, cream of tartar, and chlorate of potash; or with a mixture of galls, hard sugar, and chlorate of potash, so as to form a powerful blasting powder or explosive compound.
" 28	98,425			Tal. P. Shaffner.	Process for manufacturing nitro-glycerine.
" 28	98,426			" "	Process for preserving nitro-glycerine by absorbing it with sponge or other equivalent elastic porous substance; one pound of sponge may be mixed with five pounds of nitro-glycerine.
" 28	98,427			" "	Gun-cotton treated with nitro-glycerine, by preference one pound nitro-glycerine to one pound of gun-cotton. Also claims combination of nitro-glycerine with nitrated fibre.
1870. January 18	98,854			Carl Dittmar.	Dualin. A mixture of cellulose, nitro-cellulose, nitro-starch, nitro-mannite, and nitro-glycerine. Cellulose prepared by reducing wood of a soft texture (for instance, pine or poplar) to small grains resembling sawdust, and treating them with diluted acids, and then boiling them in a solution of soda.

* See paper also by Stephen Chester on "Nitro-glycerine, its Manufacture and Use," read before the American Society of Civil Engineers, June 2d, 1869. Published in the Transactions of the Society, vol. i.

ORIGINAL PATENTS.		REISSUES.		NAME OF PATENTEE.	NAME AND DESCRIPTION OF EXPLOSIVE.
DATE.	NUMBER.	DATE.	NUMBER.		
1870. January 25	99,069			Carl Dittmar.	Xyloglodine. Consists of nitric and sulphuric acids, and of glycerine-starch, or glycerine-cellulose, or glycerine-mannite, or glycerine-benzole, or analogous substances. Claimed to differ in certain characteristics from nitro-glycerine.
" 25	99,070			" "	Process for manufacturing xyloglodine.
June 14	104,217			H. Julius Smith.	Improvement in electric fuse-heads.
August 23	106,606			George M. Mowbray.	Process for manufacturing nitro-glycerine.
" 23	106,607			" "	Process for manufacturing nitro-glycerine, nitro-benzole, etc.
December 20	110,855			Joseph Hafenegger.	Fatty or oily substances in intermixture with explosive compounds, to prevent spontaneous or premature explosion. Invention relates particularly to mixtures containing chlorate of potash or other highly explosive chemical ingredients, liable, when exposed to atmosphere or friction, to produce premature explosion.
1871. February 7	111,642			" "	Invention relates to certain diluents or ingredients to be mixed and incorporated with chlorate-of-potash powders. Four oxides are used, but one or more can be dispensed with; oxides of lead and manganese preferred. Claimed that these mineral oxides, by the supply of oxygen they give off when heated, promote and greatly enhance the force of the chlorate-of-potash compounds. Should be diluted with fatty, oily, or resinous substances to give safe handling.
March 21	112,848			Edw. A. L. Roberts.	Process for manufacturing nitro-glycerine.
" 21	112,849			" "	" " " "
" 21	112,859			H. Julius Smith.	Electric fuses.
November 7	120,776			Edw. A. L. Roberts.	Asbestus powder. Combination of nitro-glycerine with asbestus as an absorbent. Other kinds of powder, if of sufficient permanence, may also be mixed with the compound, or with asbestus alone, such as common gunpowder, white gunpowder, nitro-cellulose, etc. For part of the asbestus, clay, plaster, infusorial silica, chalk, etc., may be substituted.
December 12	121,898			" "	Process for manufacturing nitro-glycerine.
December 26	122,245			Edwin Gomez.	Explosive compound composed of sugar of lead (acetate of lead), prussiate of potash, and chlorate of potash. Invention claimed to be a modification and improvement upon Letters Patent No. 18,199—chlorate of potash, nitrate of lead, and ferrocyanide of potash; and Letters Patent No. 86,980—chlorate of potash, sugar of lead, prussiate of potash, and nitrate of iron.
1872. March 5	124,397			Carl W. Volney (assignor to Geo. M. Mowbray).	Nitro-toluol compound. Explosive consisting of nitro-glycerine and nitro-toluol or nitro-benzole. Nitro-toluol manufactured similarly to nitro-glycerine, but with the substitution of commercial benzole for glycerine. The final explosive compound composed of three parts nitro-toluol, dissolved in seven parts nitro-glycerine.
March 12	124,510			Robert Punshon.	Invention consists in coating, covering, or incorporating the particles or fibres of gun-cotton with sugar, either raw or refined, in such a manner as to separate or isolate the particles or fibres of the gun-cotton. This invention has for its object to regulate the rapidity of the explosion of gun-cotton, so as to render it suitable for use in guns for military and sporting purposes.
June 25	128,450			John D. Muschamp.	Explosive compound. Wood fibre treated with nitrous or nitric acid and sulphuric acid.
August 6	130,123			C. Feodor Fuchs and Arminius Clement.	Explosive compound consisting of a mixture of chlorate of potassa and finely ground tortoise or turtle shell, in addition to saltpetre, sulphur, and charcoal.
November 12	131,040			Francis X. Lowallce.	Instrument for charging drill-holes.
1873. April 1	137,439			Alex. Hamar.	Improvement in cans for transporting nitro-glycerine. A can provided with a discharge-nozzle, and with a vent-tube having one or more funnel-shaped diaphragms for the escape of gases created within the can.
" 1	137,440			" "	Process for manufacturing nitro-glycerine.
May 13	138,841			Treat S. Beach.	Rend-rock. Explosive compound made by combining one or more of the following substances: First, an alkaline nitrate or some salt which will produce substantially the same result; second, nitro-glycerine or some of the equivalent nitro-substitution products; third, wood-fibre or other material containing cellulose; fourth, paraffine or equivalent wax-like material, such as asphaltum, pitch, resin, spermaceti, wax, and the like. Proportions suggested are, nitrate of potash 40 parts, nitro-glycerine 40, wood-fibre 13, paraffine 7. Pitch may be substituted for the paraffine; use of small quantities of sulphur and charcoal advised.
May 20	139,192			Edw. A. L. Roberts.	Process for so treating detonating compounds as to render them comparatively safe to handle, by mixing them with water or other fluids, or hydroscopic and other salts or materials which attract or absorb and retain water.
1873. June 3	139,452			James Burson.	Apparatus for submarine blasting. Object of invention is to provide a temporary cap or cover of large dimensions for the charge to be exploded—this cap is intended to be submerged by its weight, and to maintain and direct the charge of powder or other explosive against the rock.

ORIGINAL PATENTS.		REISSUES.		NAME OF PATENTEE.	NAME AND DESCRIPTION OF EXPLOSIVE.
DATE.	NUMBER.	DATE.	NUMBER.		
1873. June 3.........	139,468	....	....	Egbert Judson, assignor to the Giant Powder Co. and to the Atlantic Giant Powder Co.	Giant Powder No. 2. 40 parts by weight of nitrate of soda, 6 parts by weight of rosin, 6 parts by weight of sulphur, 8 parts by weight of infusorial earth, or other analogous absorbent substances. These ingredients dried, separately pulverized, and then intimately mixed—to this mixture 40 parts nitro-glycerine added. Instead of nitrate of soda, other nitrates, such as nitrate of baryta, nitrate of lead, or nitrate of potash, may be used; also, in place of rosin, other carbons and hydrocarbons, such as bituminous coal, coke, charcoal, flour, starch, sugar, lignite, wood, and asphaltum. Absorbent preferred is infusorial earth. Proportion of nitro-glycerine may vary from 10 per cent by weight of the mass up to largest percentage that the dry mixture will permanently retain. Claimed that the mixture is more powerful than a mere mixture of the same amount of nitro-glycerine with infusorial earth, owing to the presence of the nitrate, carbon, and sulphur. (See p. 73.)
" 10........	139,738	....	....	Tal. P. Shaffner.	Combination of gun-cotton or other nitrated fibrous substances with nitrated water or liquids, or paraffine, or beeswax or its equivalent.
" 10........	139,746	....	....	Thomas Varney.	Process for so preparing dynamite that it can be exploded when frozen. Dynamite frozen in solid cakes cannot be exploded without great difficulty, but claimed that frozen dynamite prepared in small grains by a suitable process (as described) can be exploded with a percussion-cap containing about three times the ordinary quantity of fulminate.
August 5.......	141,455	....	....	Alfred Nobel.	Giant Powder No. 2. Mixture with nitro-glycerine of a pulverized nitrate (such as the nitrates of soda, potash, baryta, or lead) and a pulverized carbon or hydrocarbon, such as coal, resin, sugar, starch, etc., with or without the addition of pulverized sulphur. Following proportions may serve as a type from which variations can be made according to strength of explosive required and warmth of climate in which it is to be used: By weight in parts, 70 nitrate of soda, 10 pulverized resin, 20 nitro-glycerine. To these may be added from 5 to 10 flour of sulphur. Instead of nitrate of soda, either of the nitrates of potash, baryta, or lead may be employed, and instead of resin, other carbons and hydrocarbons, as coal, sugar, starch, wood, charcoal, etc.
" 5.......	141,585	....	....	Johann H. Norrbin and Johann Ohlsson, assignors to Alarik Liedbeck.	Explosive compound. Nitrate and nitrite of ammonia mixed with a fulminate such as nitro-glycerine, nitro-mannite, or picrate of potash. Nitro-glycerine preferred with nitrate of ammonia. Best composition claimed to be by weight in parts, 30 nitrate of ammonia, with 6 to 8 coal, then add 10 to 20 parts nitro-glycerine (more or less, according as increased power and quickened detonation may be desired).
December 9....	145,408	....	....	Carl Dittmar.	Titan. Preparation of vegetable fibre for manufacture of explosive compounds. Fibre reduced to pulp, compressed, then granulated and treated with acid or acids for rendering it explosive. Also vegetable fibre prepared with a solution of sugar, or mannite, or amyline, or inuline, or other substances, as by process described, then rendered explosive by nitric acid.
....	....	1874. February 10....	5,759	....	Titan.
1874. January 20....	146,530	....	....	Walter N. Hill.	A blasting powder or dynamite, composed of a mixture of nitro-glycerine and a silicious powder, the latter being prepared by precipitation from a solution of silicates.
March 10.......	148,838	....	....	Thomas Varney.	Electric fuse.
May 5	150,428	....	....	George M. Mowbray.	Mica Powder. A combination of nitro-glycerine with finely-divided mica or muscovy talc, without confining the invention to any specific proportion of the materials. (See p. 88.)
July 14.........	153,086	....	....	Charles L. Kalmbach.	Fulgurite. Nitro-glycerine mixed with some coarsely ground farinaceous substance, corn-meal by preference, in varying proportions. Perhaps most serviceable proportion is 4 parts corn-meal to 6 of nitro-glycerine, but it is found convenient sometimes to use but 1 part corn-meal to 9 of nitro-glycerine, when it is wanted thin enough to pour. Claimed that, being nearly pure starch, large volume of gas yielded when heat of explosion acts on compound, thus nitro-glycerine sensibly assisted.* Also patent claims a method of packing nitro-glycerine at ordinary temperatures and in a fluid state, for shipment in non-metallic vessels, closed if need be, but holding with the nitro-glycerine at least an equal amount in bulk of atmospheric air; also stowing nitro-glycerine when not in transit in perpendicular or flaring-sided open vessels of similar material, and covering only with a thin film of water. The kind of vessels preferred being well-glazed earthenware vessels, called crocks in the trade. Patent asserts distinctly that nitro-glycerine when transported frozen is peculiarly liable to explosive compression; also that it should never be kept or carried in thin metallic cans—tin for instance.

* If the carbon here adds strength, it is not in the sense of a true explosive dope (see p. 73), for there is no free oxygen present except the slight excess in nitro-glycerine to combine with it.

Original Patents. Date.	Original Patents. Number.	Reissues. Date.	Reissues. Number.	Name of Patentee.	Name and Description of Explosive.
1874. November 17...	157,054	....	....	Joseph W. Willard.	Hercules Powder. Explosive compound composed of carbonate of magnesia, nitrate of potash, chlorate of potash, sugar, and nitro-glycerine. Ingredients mixed about as follows : GRADE NO. 1. — PARTS. Carbonate of Magnesia........ .... 20·85 Nitrate of Potash........................ 2·10 Chlorate of Potash...................... 1·05 White Sugar............................. 1·00 Nitro-glycerine........ .... 75·00 100·00 GRADE NO. 2. — PARTS. Carbonate of Magnesia.................. 10·00 Nitrate of Potash................ ...... 31·00 Chlorate of Potash...................... 3·34 Sugar.................................... 15·66 Nitro-glycerine.... .... 40·00 100·00
" 24....	157,143	....	....	Carl W. Volney.	Volney's Powder. Explosive compound composed of nitrated naphthaline mixed with an oxidizing agent, the nitrated naphthaline being obtained by the action of nitric acid upon naphthaline.
December 15...	157,856	....	....	Isaac M. Milbank.	Fulminating compound composed of the ingredients, chlorate of potash, charcoal, and red phosphorus, to be used in caps, primers, and cartridges. Following proportions found to be reliable and safe : chlorate of potash 80 parts, charcoal 85, red phosphorus 4½.
" 15...	157,857	....	... .	" "	Fulminating compound for caps, primers, and cartridges, composed of chlorate of potash, prussiate of potash, and red phosphorus. Following proportions used : chlorate of potash 20 parts, prussiate of potash 10, red phosphorus 1.
1875. February 23....	160,058	....	... .	Edward Greene.	Process for manufacturing gunpowder. Distinctive feature is in method of incorporating the ingredients, consisting in dissolving the saltpetre or nitrate of soda in hot water, and mixing the other ingredients with the heated solution, etc., this being done in a vacuum or partial vacuum.
June 8........	164,262	....	....	Prudencio Castellanos.	Apparatus for recovering acids from the residuum of nitro-glycerine manufactured.
" 8.........	164,263	....	....	" "	Explosive compound, consisting of nitro-glycerine, nitrobenzole or benzine, fibrous material, and pulverized earth. Claims that addition of the nitro-benzole gives the nitroglycerine property of burning easily and rapidly without explosion ; also that nitro-benzole reduces somewhat the point of congelation of the nitro-glycerine.
" 8...	164,264	....	....	" "	Explosive compound or powder, consisting of nitroglycerine, nitrate of potash or soda, picrate, sulphur, a salt insoluble and incombustible in nitro-glycerine, and carbon. The incombustible salts used may be silicates of zinc, magnesia, and lime, oxalate of lime, carbonate of zinc, etc.—the soluble and explosive salts used are all the mineral and organic picrates—also addition of proportions of potash, carbon, sulphur, etc., found useful—taking care, however, not to use sulphur and chlorate of potash in any one compound. Object of the incombustible salt is, by mixing with it, to render the nitro-glycerine inert and safe ; the explosive salts are mixed with this inert compound, and their office is to so permeate and occupy every part of it that when the charge is ignited by a detonator, a complete and sustained combustion of the whole mass may take place, resulting in its total explosion. The following proportion of parts is suggested : nitro-glycerine 40, nitrate of potash or soda 25, a picrate 10, sulphur 5, a salt insoluble and incombustible in nitro-glycerine, as described, 10, carbon 10. Total, 100.
September 7....	167,508	....	....	Herrenstein Courteille, assignor by mesne assignment to the Triumph Safety Powder Co., of Baltimore, Md.	Safety Powder. Essential principle of invention consists in mixing a comparatively large volume of the elements of common gunpowder with a small volume of such other elements as will, under the proper conditions, combine with the nitrogen, oxygen, and sulphur of the gunpowder to form nitro-glycerine or the equivalent thereof, the nitro-glycerine elements remaining chemically uncombined as nitro-glycerine until the mixture is exploded in a close chamber or under pressure.* Following proportions of ingredients have proved best : For manufacturing 100 pounds—nitrate of soda or saltpetre 60 to 70, sulphur 10 to 12, charcoal 7 to 10, peat and hard coal 9 to 12, combined metallic sulphates 2 to 4, and oleaginous matter, animal or vegetable, refined or crude, 1 to 2. Tar in any form will answer the purpose of such oily matter.
....	....	1876. April 18........	7,068	Herrenstein Courteille.	Safety Powder.

* Whether this claim is substantiated in practice, the author cannot say from experience ; but, theoretically, it would appear hardly possible that nitro-glycerine could be formed as proposed in this patent.

ORIGINAL PATENTS.		REISSUES.		NAME OF PATENTEE.	NAME AND DESCRIPTION OF EXPLOSIVE.
DATE.	NUMBER.	DATE.	NUMBER.		
1876. April 4........	175,735	....	....	Alfred Nobel.	Gelatinated nitro-glycerine. Prepared by dissolving in nitro-glycerine, when gently heated, nitrated fibre, such as gun-cotton, or collodion cotton, or other substance serving the same purpose, object being to convert the liquid nitro-glycerine to a solid or semi-solid consistency more conducive to safety and offering greater facility for use.
" 11.........	175,929	....	....	James Coad.	Nitro-glycerine compound, of several grades. Most powerful kind—in parts: nitro-glycerine 75, nitre 5, nature-decayed wood 20. Powder of less power as follows—in parts: nitro-glycerine 30, nitre 50, nature-decayed wood 20. Another class—in parts: nitro-glycerine 30, common blasting powder 60, nature-decayed wood 10.
May 30.........	177,988	....	....	Carl Gustaf Björkman.	Explosive compound, consisting of, in parts, nitrate of potash 20, chlorate of potash 20, cellulosa 10, pea-meal 10, sawdust 10, nitroline 30. Cellulosa is made by mixing 20 parts nitric acid, 1·50 specific weight, with 40 parts sulphuric acid, 1·845 specific weight, left for 48 hours, then 12 parts well-ground pea-meal added, stirred until temperature has fallen 6° Fahr. from that at which it stood when pea-meal added. Left standing two hours, then poured into vessel containing five times its weight of water and left ten minutes; then water poured off and fresh supply impregnated with soda poured on while compound is stirred. Left standing until cellulosa sinks, water drained off, cellulosa placed in room with temperature 63° Fahr., where it is kept and stirred for 12 hours, then ready for use. Nitroline made as follows: 80 parts nitric acid, 1·5 specific weight, mixed with 170 parts sulphuric acid, 1·845 specific weight. Mixture left standing until temperature has fallen 10° Fahr., then 15 parts raw stearic oil and 15 parts syrup slowly dropped into the acids, which are kept stirred. Time for this process is about six hours, then left standing four hours, during which raw nitroline will rise to surface; skimmed, deposited in vessel containing water at least five times weight of compound, left two or three minutes; thereafter charged with fresh water, then water containing 10 per cent soda and four times weight of compound is poured on under continual stirring. Left standing short time, when nitroline is taken out and placed in a room with a temperature of 40° Fahr., and it is ready for use. The compound is exploded as follows: charge is deposited in a paper cover by the aid of a piece of wood conically shaped. The cartridge is placed in a hole bored in the rock, pushed well down to the bottom, covered with half an inch of powder, in which a fuse is inserted. Then covered with clay or sand, the fuse is ignited, and when the fire reaches the powder the explosion follows.
October 31.....	183,764	....	....	Egbert Judson.	Judson Powder. This explosive is a mixture of nitro-glycerine with various explosive salts, but it differs from those previously made in that the grains or particles of the absorbent are coated, cemented, varnished, or smeared with some combustible substance offering resistance to the absorption of nitro-glycerine and of water. The object of this coating is to save and render effective that proportion of nitro-glycerine which, with ordinary "dry" (so-called) absorbent mixtures, is so closely absorbed and taken up that it is rendered practically inexplosive. The result of using such a coating has been found to be, that the proportion of nitro-glycerine used in the compound may be much lower, that in fact one, two, or three per cent only of nitro-glycerine will give a powerful explosive compound; or the proportion may be increased at pleasure up to 15 per cent or more. On the other hand, it is known that with the ordinary "dry" absorbents, containing explosive salts, seldom less than 15 per cent of nitro-glycerine is found effective, and in fact from 30 to 40 per cent are generally used. The following is an example of such a coated or varnished absorbent, in parts, by weight: sulphur 15, resin 3, asphalt 2, nitrate of soda 70, anthracite coal 10. Let the sulphur, resin, and asphalt be melted together and well stirred. Into this mixture while melted the nitrate of soda and the coal, both pulverized and thoroughly dried, are to be mixed and well stirred until thoroughly varnished, cemented, or coated by the melted mixture, care being used that the degree of heat be not sufficient to create danger of firing the mass. It is better that both nitrate and coal should be hot when introduced. The entire mixture should thereafter be gently stirred until so cool that the grains would cease to adhere to each other. The mixture is then complete and ready to receive the nitro-glycerine, which may be added as desired.

ORIGINAL PATENTS.		REISSUES.		NAME OF PATENTEE.	NAME AND DESCRIPTION OF EXPLOSIVE.
DATE.	NUMBER.	DATE.	NUMBER.		
					The ingredients which form the coating, varnish, or cement may be applied without first melting them. To do this, first grind each of the materials of the dry mixture. Then, leaving out the carbon, mix the others all together, and proceed to heat them well, all the time stirring, and continue until the whole is thoroughly varnished, cemented, or coated. While the mixture is cooling, the stirring must be carefully continued until the grains cease to adhere to each other; then add the pulverized carbon, which must be perfectly dry, mix well, and afterward put in the nitro-glycerine. When carbon is used that is not porous or absorbent, it is not necessary that it should be varnished, cemented, or coated. In that case, it may only be necessary to varnish, cement, or coat the nitrate of the mixture. While this mixture above described may not be entirely non-absorbent after it has been treated by the coating process, it is claimed to be sufficiently so as to mainly counteract the absorption of the nitro-glycerine, as well as to check the tendency to deliquescence in the original salts themselves. It should be understood that the term "non-absorbent" above used is simply employed in contradistinction to the ordinary class of absorbents of this nature which are not coated. Same re-issued January 30, 1877. No. 7,481.
1876. November 7....	184,020	....	....	Joseph Paul Raymond Toch....................	Slowly exploding compound of, by weight: spent tan 3 parts, wood sawdust 5, nitrate of soda 3, nitrate of baryta 3, charcoal 3, sulphur 12, saltpetre 68. Claimed that compound is difficult to explode by concussion, and that the nitrate of baryta utilizes the sulphurous compounds.
1877. February 6.....	187,155	....	....	S. J. Mackie, Camille A. Faure, and G. French..	Mixture of finely-divided nitro-cellulose 25 parts, nitrate of baryta 18.5 parts, and nitrate of potassa 6.5 parts. Nitro-cellulose should be reduced to an impalpable powder.
March 6........	188,124	....	....	J. Goetz	Mixture of an explosive base with glucose, uncrystallizable sugar, or syrupy solution, to prevent premature or accidental discharges. Proportion may be: 10 parts chlorate potash, 10 parts glucose in solution, 3 parts powdered charcoal, 2 parts powdered sulphur, 1 part amorphous phosphorus, 3 parts picrate lead.
" 27.......	188,724	....	....	J. Goetz	The glucosides, in form of molasses, syrup of glucose, or solution of grape sugar, are mixed with compounds of gas-producing or explosive substances, especially with chlorate of potash in connection with any combustible substances. Preferable constituents are: chlorate of potash 10, solution of glucose 10, powdered charcoal 3, powdered sulphur 2, amorphous phosphorus 1, picrate of lead 3. Claimed that compound will stand all ordinary shocks, handling, and transportation, without danger of premature exploding. Burns with a bright light when unconfined.
May 22.........	190,954	....	....	Otto Burstenbender........	Prepared by inspissating vegetable substances with glycocole ($C^4H^4NO^2+H$), or chondrin and saltpeter, then soaking in nitro-glycerine, granulating and drying. Vegetable substances adapted are, cellulose, pith of plants and trees, pulp of fruits, fungi, vegetable excrescences, punk, and other soft, spongy, elastic vegetable substances. Such substances are dried, pulverized, then inspissated with glycocole or chondrin and saltpeter, and mixed with 20 to 60 per cent nitro-glycerine. Claimed to show tendency to coagulate, and is easily granulated through sieves and dried. Claimed, when dry, heat does not affect the combined nitro-glycerine; that grains will not freeze together at temperature below zero, nor flow together or exude nitro-glycerine at 200°, and that this is due to glycocole or chondrin present, and that combustion is slower than in dynamite, and better adapted for rending power.
November 20...	197,267	....	....	Sanford O. Gotham	Compound prepared of chlorate potash 10 ounces, nitrate potash 2 ounces, powdered oak bark 5 ounces, 17 ounces of above compound incorporated with 20 to 35 per cent nitro-glycerine free from acid, and then sifted through fine sieve.
1878. February 12....	200,272	....	....	S. ¯ Fowler	Object of patent to prepare combination of nitrate of ammonia in which latter does not deliquesce, and at low cost. First compound prepared of 75 parts nitrate ammonia with 25 parts non-hydrated sulphate soda, by double decomposition of sulphate ammonia and nitrate soda, and by process described at length in patent. Explosive compound preferred is prepared by mixing 75 parts of above compound with 20 parts nitro-glycerine and 5 parts charcoal or its equivalent. Compound may also be prepared by using gun-cotton or nitro-methyl, instead of nitro-glycerine.

Original Patents.		Reissues.		Name of Patentee.	Name and Description of Explosive.
Date.	Number.	Date.	Number.		
1878. March 19	201,520			William Graham and Emery Ward	Compound of 16 ounces yellow prussiate potash, 40 ounces chlorate potash, 20 ounces white sugar, 1¼ ounces red lead. Pulverize ingredients before using, and add first the red lead, either of the potash salts; then add other potash salt and the white sugar. Claimed that red lead obviates danger of premature explosion. Also makes combustion slower, and can be used when wet and doughy.
May 7	203,482			Edward Monakay	Equal parts mixed of ashes, lamp-black, earth, nitrate soda, and borax, and to every pound of this mixture add half a gill kerosene oil. To this add nitro-glycerine in quantity according to strength of explosive desired. Claimed that fluid hydrocarbon diluent so dilutes and modifies nitro-glycerine as to obviate accidents before required for use, and when compound exploded, this diluent converted into an explosive vapor contributing to effectiveness of compound.
November 26	210,197			Philip M. Gallaher, Willet Lloyd, and George S. Walker	Mixture preferred is 70 to 80 parts nitrate soda or potash, 6 to 12 parts sulphur, 8 to 16 parts charcoal, 1 to 3 parts sulphate iron, ⅛ to 1 part sulphate copper, 8 to 14 parts ground bark. Claimed less dangerous than ordinary blasting powders; also not ignited by friction or concussion.
1879. February 25	212,726			Wesley Miller	35 parts nitrate soda, 25 parts nitrate potash, 2 parts starch, are mixed, forming compound No. 1; 3 parts bichromate potash, 13 parts sulphur, 12 parts charcoal, mixed, form compound No. 2. (These ingredients separately ground to fine powder.) Blasting powder is composed of 18 parts No. 1 mixed with 7 parts No. 2 in two complementary parts or divisions, which are harmless when separated and explosive when mixed.
May 6	215,199			Adolf Dieckerhoff	Object of invention to increase explosive strength of gunpowder without increasing its liability to accidental ignition. Consists in mixing gunpowder with small proportion (not over 15 per cent) of precipitated alkaline picrate or picrates. Proportions are: 100 parts of weight of compound contain 1 to 15 parts picrate precipitate, and 85 to 99 parts gunpowder. Regards mixture of nitrate with sulphur and picrate in above general proportions, without charcoal, as practically equivalent to above, as experience has shown charcoal not essential to the compound.
" 13	215,395			John R. Powell	Safety Squib for blasting with gunpowder in coal.
June 3	216,137			Gustav Bloem	Blasting Fuse. Detonating primer in which an outer cap or shell, charged with fulminating compound, is combined with an inner cap having hole at inner or closed end, and fuse fitted into inner cap.
August 19	218,762			Alfred Monnier	Explosive compound of 71 parts chlorate potash, 16 parts sugar, 6 parts ground charcoal, 7 parts coal tar. Chlorate potash is dissolved in 250 parts water, and substances ground and mixed in apparatus described. Claimed that by wet process danger avoided in manufacture. (Re-issued April 27, 1880. No. 9,173.)
October 7	220,304			John Pattison	Mixture of chlorate of potash explosives with greasy vegetable flour or meal, to lessen liability to explode and yet allow the powder to remain granular.
December 2	222,169			Edward J. Williams	Following substances finely pulverized by pressing through No. 80 sieve: 3 pounds chlorate potash, 1 pound prussiate potash, two ounces bichromate potash, 5 ounces nut-galls, 2 ounces cannel-coal, 6 ounces starch, also 5 ounces crude coal-oil.
		1880. April 27	9,173	Alfred Mounier	See No. 218,762, August 19, 1879, above. In re-issue, descriptions fuller and no proportions noted.
1880. April 27	226,867			Frederick Mann	Improvement in manufacture of nitro-glycerine by subjecting the ordinary mixture of acids and glycerine to freezing temperature. Nitro-glycerine is frozen or crystallized out, and separated in centrifugal machine. Freezing aided by adding first time a teaspoonful of previously frozen nitro-glycerine. Frozen nitro-glycerine then liquefied, washed in cold water and purified from acid by repeated washings, and lastly in weak and cold alkaline solution.
May 11	227,601			Robert J. Warren	Add 1 part nitro-cellulose (either mononitro, dinitro, or trinitro) to 10 parts nitro-glycerine, producing coagulated mass. Allow to stand until nitro-cellulose all dissolved without heat. Then mix in carefully pulverized trinitro-cellulose until mass brought to consistency of dry powder. Then add pressed and glazed gunpowder. Proportion latter depends on character of compound required. If much, explosion will be slow; if little, then its chief function will be to promote explosion of compound, and properties of other components will predominate. 70 gunpowder to 30 of above, gives a blasting powder. One of the main objects of compound is to keep the added gunpowder dry.
August 3	230,820			William S. Rosecrans	Exploder.

ORIGINAL PATENTS.		REISSUES.		NAME OF PATENTEE.	NAME AND DESCRIPTION OF EXPLOSIVE.
DATE.	NUMBER.	DATE.	NUMBER.		
1880. September 21	232,381			Max Tschirner	57 parts picric acid and 43 parts chlorate potash separately triturated, then well incorporated together with addition of 5 per cent pulverized rosin. Sprinkle product with sufficient quantity benzine, kerosene oil, or other fluid to moisten it, and which will dissolve the rosin and pass off quickly while mass is stirred, which should be kept up till benzine is evaporated and compound becomes a plastic mass, easily moulded.
" 28	232,640			Robert F. L. Hallock	New system of blasting with making drill-hole to receive charge. Explosive is placed on a surface of rock, and water inclosed in a water-proof bag laid over it. Claimed the bag of water exerts effect of water in submarine blasting, causing effect of blast to be exerted downwards. Claimed bursting of water-bag allays and condenses powder fumes.
November 16	234,489			Charles A. Morse	Nitro-glycerine and rosin dissolved in a common solvent. Solvent then evaporated or eliminated, giving explosive compound of nitro-glycerine and resinous or equivalent substance formed into a hard, dry, solid, granulated, or pulverized mass.
December 28	235,871			William Heick, assignor by mesne assignment to the Thunder Powder Co.	Honey and glycerine, treated with nitric and sulphuric acid. This compounded with chlorate of potash, nitrate of potash, prepared sawdust and prepared chalk, in two proportions giving No. 1 and No. 2.
1881. January 18	236,714			Charles A. Morse	Nitro-glycerine and a resinous substance, dissolved in a common solvent: then mixed intimately with nitre or other oxidizing substance, and solvent then evaporated; residue granulated.
March 15	238,916			Frederick C. Keil, assignor by mesne assignment to the Thunder Powder Co.	Nitro-glucose (dextro-glucose made from starch) subjected to certain treatment, and compounded with nitrate of potash, chlorate of potash, and prepared vegetable fibre.
April 26	240,516			Lafayette Hinckley, Francis C. Treadwell, administratrix of said Hinckley deceased	Method of rendering nitro-glycerine and its compounds non-explosive by ordinary shocks, by confining it in closed vessels, tubes, cartridges or shells under pressure.
May 10	241,163			True P. Sleeper	Compound of chlorate of potash, sugar and charcoal.
" 24	241,941			Gilbert S. Dean	Method for increasing safety in handling or transporting nitro-glycerine, consisting in mixing it with a pulverulent nitro-compound and water. Preferred proportions are 100 parts nitro-glycerine, 10 parts pulverulent nitro-cellulose or nitro-dextrine, and from 2 to 3 parts water, stirred together, forming pasty mass, ready to be inserted into blasting-cartridges.
June 14	242,783			John M. Lewin	Pasty mass, comprising cellulose and nitre, incorporated with nitro-glycerine, and being a plastic, gelatinized, nitro-glycerine compound, comprising in combination with nitro-glycerine an inexplosive gelatinizing material and an oxidating salt.
" 28	243,432			Silas R. Divine, assignor to Rend Rock Powder Co.	Solid ingredient, such as chlorate of potash, and a liquid ingredient, such as nitro-benzole, mechanically united substantially in proportion of 3 to $4\frac{1}{2}$ parts solid ingredient to 1 part of liquid ingredient.
" 28	243,433			Silas R. Divine, assignor to Rend Rock Powder Co.	Improvement in blasting, consisting in saturating inexplosive solid ingredient (such as chlorate of potash) deposited in cylindrical cartridges with porous envelopes, with a liquid ingredient before placing cartridge in drill-hole. Also patent for improved blasting cartridge of porous material, containing solid substance, which is saturated with a liquid, such as nitro-benzole.
July 19	244,575			Camille A. Faure and George French, assignors to the Cotton Powder Co. (limited) of Westminster, England	Intimately mixed carbonaceous and oxidizing materials, in granular form, with finely-divided nitro-cellulose, distributed around the granules. Detonation of the nitro-cellulose through the mass gives its explosive effect, at the same time igniting the mass of granules.
November 15	249,490			Carl W. Volney, assignor to the Volney Chemical Co.	Mixture of monochlordinitrin or chlorpropenyldinitrate with nitrates and chlorates of potassium, sodium, barium, or other alkaline metals, and vegetable fibre or charcoal. (Concentrated glycerine is saturated with hydrochloric acid gas, giving propenylchlorhydrate or glycerine chlorhydrin; which is incorporated into a mixture of sulphuric and nitric acids, giving monochlordinitrin or chlorpropenyldinitrate.)
" 15	249,701			Thomas Varney	Absorbent for nitro-glycerine powder, made by mingling with fine particles thereof small proportion of fusible, soluble, or paste-producing material as a coating. This, when hardened, holds the attached particles in aggregations, which are coated with and measurably absorb nitro-glycerine, and form explosive powder containing very small percentage of nitro-glycerine.
December 20	251,145			Gustav Von Planite, assignor to the Nitresine Manufacturing Co.	Absorbent or base for explosives, formed by the combination of nitric acid and resin.

CHAPTER IV.

THE PRINCIPLES OF BLASTING,* WITH NOTES OF TUNNELS DRIVEN BY HAND-LABOR AND BLACK POWDER.

WE have seen, in Chapter II., the successive steps in the history of blasting, after the early introduction, in 1613, of gunpowder into mining by Martin Weigel, Mine Superintendent at Freiberg; how at first they only bored wide holes of 2 to 2½ inches diameter, using the crown [Fig. 17(*a*)] and cone [Fig. 17(*b*)] bits exclusively; how chisel-bit drills were not introduced until long afterward (we know they were brought from Hungary to the Harz in 1749), and how the holes at first were stopped by a wooden plug, clay tamping not being used until, perhaps, nearly a century after the introduction of drilling. And after clay tamping was introduced, it was not until 1831 that Bickford invented the safety-fuse. All through that long intermediate period, reed or rush fuses, etc., were used in Germany, and many accidents constantly occurred from the friction of the iron and metallic needles used; and we have seen how copper needles and those of soft metallic alloys were substituted to lessen this danger. In England, the same trouble was experienced, as the following extract from the evidence of John Taylor, before the "Select Committee of the House of Commons on Accidents in Mines," will show.†

FIG. 17(*a*)

FIG. 17(*b*).

"Q. Have the goodness to describe the former practice of blasting and the present." (This was in 1836, or five years after the invention of Bickford's fuse.)

"A. The blowing rock by gunpowder is a simple process; the hole is bored into the rock, and in such direction as to expose the weakest part to the action of the powder; this hole is charged with a certain portion of gunpowder and is then filled with clay, or more usually with a soft kind of rock, which is rammed into it, leaving a small orifice, through which the rush or fuse is afterward introduced for setting fire to it. The most dangerous part of this process is the ramming in of this soft rock to confine the powder, which is technically called tamping; this used to be done with an iron bar, and the bar striking silicious portions of the rock inflamed the powder, exploding it, thereby injuring and perhaps killing the men.

"The first improvement was in making that bar of copper, or a part of it of copper; still, the *needle* or small *rod* which is introduced in the tamping to preserve the orifice for blasting was of iron, and that sometimes inflamed the gunpowder; some years ago, we substituted copper instead of iron, and in doing so had very great difficulty with the men. . . .

"The copper needle is now generally used, which is the second improvement that has been introduced, but I think the last improvement is one of the best; it is the invention of a

* The author expresses his indebtedness to the "Lehrbuch der Gesammten Tunnelbaukunst" of Ržiha; to the "Tunnelbau" (ed. of 1874) of Schoen; and to André's "Coal Mining," for many valuable notes embodied in the following chapter. From Ržiha, and especially from Schoen, many of the illustrations have been taken. He is also indebted to Mr. E. P. North, M. Am. Soc. C. E., for a careful review and criticism of the chapter, both in the original MSS. and also in the proof-sheets.

† "Mechanics' Magazine," London, vol. xxiv., p. 412.

person in Cornwall, who has made what he calls safety-fuses, to be used instead of the usual practice of filling a rush or tube with powder, and dropping it into the hole. This person has invented a cord in which there is a thin vein of gunpowder, and the cord is covered with tar or pitch; the safety this gives is owing to a certain length burning in a certain time. . . .

"It is made so cheaply that no difficulty has been found in its introduction; the men are supplied with it so that is not worth their while to make the common fuses, and I think it is one of the most happy thoughts that has ever occurred."

Fuses used preceding the introduction of Bickford's were, among others, wooden tubes, reeds, straws, goose-quills, put together, small round paper tubes, small rubber tubes, etc., etc., filled with powder-paste, fine powder, or other readily igniting compounds. At the present day, a variety of tubular fuses is used in the coal regions of Pennsylvania, where a long iron tube is used, and the firing done with a straw or a Daddow squib. Figs. 18(*a*) to 19(*b*) show the Daddow squib as patented.

Fig. 18(*a*) shows Mr. Daddow's original patent: *a* is the match secured to the top of the tube *c*; one end *b* of the squib-tube is saturated with a solution of nitre, liquid sulphur, etc., or fitted with a match. The squib is then filled with powder, and sealed at the end *c*′. The squib-tube is an artificially prepared imitation of straw, and may be drawn from sheet brass or other ductile metal, made very light and thin, or prepared from paper or other suitable material. Figs. 18(*b*) and 18(*c*) show subsequent patents for matches for these squibs, in which (A) is a paper tube left open for the insertion of the squib, and (*a*) shows several strands of slow match. There are also other styles of matches that may be used, and Figs. 19(*a*) and 19(*b*) show a later patent of Mr. Daddow's where a narrow ribbon of copper is used as covering material for the squib—C showing the exterior of the squib, C′ the core of powder, F′ the copper ribbon, folded spirally around the core, which core may be first securely bound by a string or cotton thread H′. Passing through the core C′ is a string H, coated with mealed powder or any other combustible material, and intended to insure quick and certain ignition.

FIG. 18(*a*).

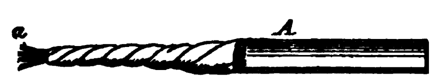


FIG. 18(*b*).

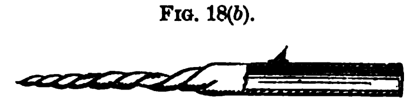


FIG. 18(*c*).

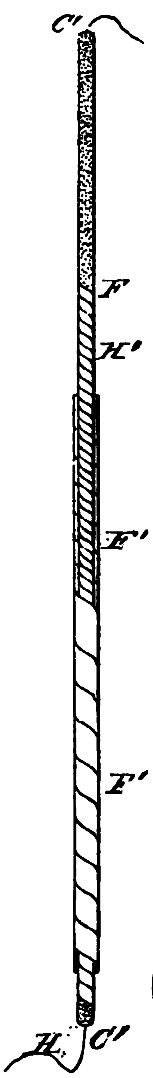


FIG. 19(*a*).

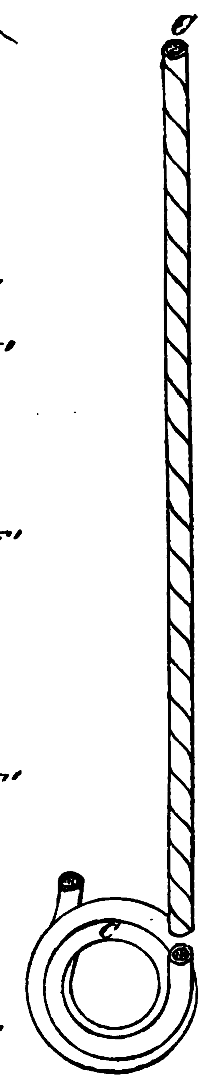


FIG. 19(*b*).

These squibs have been noted at some length, as they have of late years come into very general use among coal-miners, especially in the Schuylkill region of Pennsylvania. They are simply an adaptation of the squibs commonly made by the men, but being manufactured in quantities and with care, they are found cheap and reliable.*

* See also U. S. Patent No. 215,395, dated May 13th, 1879, for Safety-Squib invented by John R. Powell, Plymouth, Pa.

BICKFORD'S FUSE

came into general use through Europe and America soon after its invention, and still holds its place even when the higher explosives are used, in cases where it is not desired to fire several charges at once. When used with gun-cotton and nitro-glycerine or any compounds of the latter, all of which have to be detonated by a cap of fulminating powder, the fuse is slightly rasped at the end and inserted into the cap.

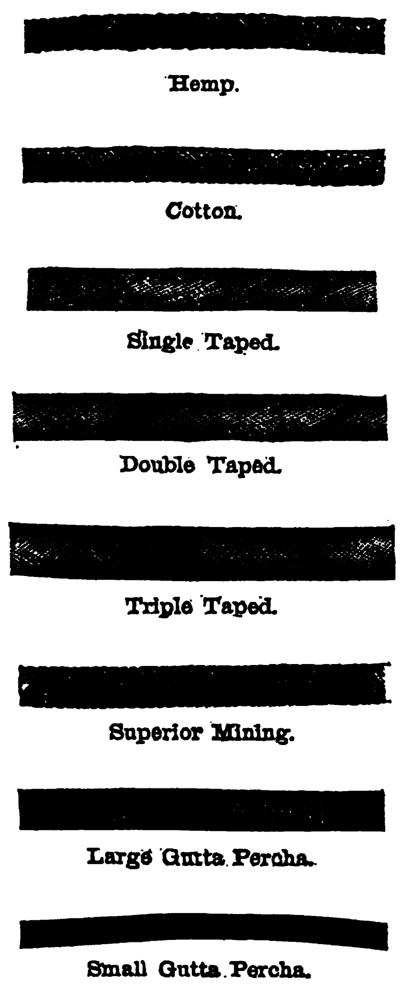


FIG. 20.

Bickford's fuse unites the following essential qualities:

(*a*) Its burning is steady and practically uniform.
(*b*) The hole may be bored to any depth.
(*c*) The men are exposed to infinitely less danger in charging than with reed fuses.
(*d*) It can be produced wholesale at reasonable rates.

The one objection that has been raised against Bickford's fuse is that the vapors are noxious, but this is a small point. Capt. Edouard Ržiha, however, of the Austrian Corps of Engineers, invented in 1862 an "odorless" so-called fuse. It has not been introduced into America. Fig. 20 shows varieties (natural size) of the fuses manufactured and sold by the Laflin & Rand Powder Company, of New York, and Fig. 21 shows a fuse inserted in a charge of black powder ready for blasting.

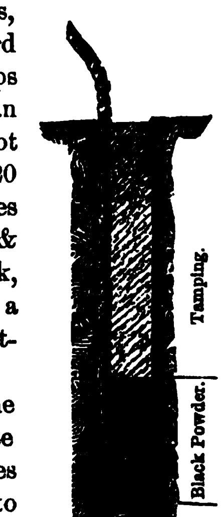


FIG. 21.

Lieutenant Isidor Trauzl, of the Austrian Corps of Engineers, whose eminent researches on high explosives led to the introduction of dynamite into Austria,* invented a dynamite fuse which was tested in 1869 with success; this fuse was simply a flexible paper tube about 5 to 6 mm. (about ¼ inch) thick, filled with dynamite, and connections being made with the different holes, it was found that, owing to the quick ignition of dynamite, a single detonation would fire the whole number of holes simultaneously. It has also been found, from the experiments of Trauzl and Peyerte, that the explosion of a small quantity of dynamite at one end of a tube will, by concussion, fire a cartridge at the other end, so that trials have also been made with hollow fuses with dynamite charges interspersed through the fuse at intervals. Electrical firing, however, is generally used for simultaneous blasting; by it, ignition of the charge is effected in two ways. One is by interposing an exceedingly fine platinum wire (iron or alloyed metal will also answer) in the path

* See Trauzl's "Explosive Nitrilverbindungen, insbesondere Dynamit und Schiesswolle" (1870); also his "Die Dynamit, ihre Eigenschaften und Gebrauchsweise" (1876); and his "Dynamit, ihre ökonomische Bedeutung und ihre Gefährlichkeit" (1876).

of a current of electricity from a powerful voltaic battery, the resistance offered by the diminished conducting power of the fine wire to the passage of the electric current heating the wire to redness, and thereby exploding the charge. Another system of electrical blasting depends upon a sudden discharge of static electricity between the terminals of two wires imbedded in a suitable priming composition, which is thereby fired. For this, various appliances have been used,* as,

(*a*) A frictional electric machine and Leyden jar.
(*b*) A voltaic battery induction coil.
(*c*) An electro-dynamic machine such as Siemens', Ladd's, Farmer's, Gramme's, etc.
(*d*) An electro-dynamic machine, as Wheatstone's, Brequet's, Saxton's, Clarke's, etc.

Baron Ebner's Austrian frictional machine for electric firing has come into general use abroad, and H. J. Smith in this country has introduced the same with some modifications, and this method has been proved by experience to be by far the cheapest and most certain method of firing a number of charges.

Another frictional battery, made by G. M. Mowbray, has also been introduced, and was used with good effect originally at Hoosac Tunnel. Static electricity is doubtless the most convenient and most expeditious mode of firing; it is questionable whether it is the most certain in quantities of over twenty or, say, thirty holes at a time. Mowbray claims, however, that his battery will fire as many as fifty charges simultaneously with safety. A fuse for static electricity depends for its value on the arrangement of the ends of the wires so that they shall neither touch nor be too far apart, and on the priming powder between the wires, its sensitiveness, etc., and, finally, of course (as in all electric fuses), on the proportion of fulminate used. Electrical firing can of course be used indifferently, in exploding charges of either black powder or of the higher explosives. Fig. 22 shows the electrical fuse so-called,

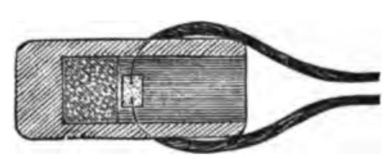


Fig. 22.

sold by the Laflin & Rand Company, and which it is claimed will cause the detonation of common blasting powder. (For discussion of detonation, see p. 196.) All of these caps or exploders are practically constructed on the same principle (p. 92), and they are chiefly used in detonating charges of gun-cotton, nitro-glycerine, dynamite, and the other nitro-glycerine compounds. Where they are used with the higher explosives, they are generally supplied by the companies manufacturing the explosive, and are made on the general type of Nobel's Hamburg caps.†

In the simultaneous blasting of several holes, after the holes have been charged (care being taken that the exploder is inserted in the centre of the charge, and that the two wires from it are long enough to reach out of the holes), the ends of two wires in each hole should be separated, and one wire of, say, the first hole joined to one of the second, and the free wire of the second to one of the third, etc., until the circuit is completed; all connections should be carefully made by twisting together bare and clean ends of the wires; finally, the free wire in the first hole is joined to one of the leading wires reaching to the machine, and the free wire of the last hole with the other leading wire (see p. 92, as to precautions

* Mowbray on Trinitro-glycerine, p. 110.

† See Engineering and Mining Journal, New York, June 17, 1882, vol. 33, p. 312, for an abstract of General Henry L. Abbott's exhaustive study of electrical fuses in his paper, No. 23, of the Professional Papers of the Corps of Engineers U. S. A., 1881.

to be used in attaching wires, etc.). Fig. 23 shows an example (actual size) of copper leading wire covered with gutta-percha. Directions for using the machines generally are sent with them. Practically, all that is necessary is to attach the crank, connect the leading wires, and,

FIG. 23.

by turning the crank and suddenly breaking the circuit, evolve and pass the igniting spark.

Among the direct advantages of electric firing may be summarized:

(*a*) Simultaneous firing of different charges.
(*b*) Premature escape of any of the gas developed absolutely avoided by close tamping.
(*c*) No smoke or gas from fuses.
(*d*) Greatest safety.
(*e*) Rapidity of work.

TAMPING

With black powder, clay is perhaps best, but soft rock, sand, etc., are often substituted. The idea of using plugs, cones, and similar devices for blocking the hole is apt to be periodically revived by enthusiastic inventors; we have seen (Tab. p. 52) how their history dates back through the last two centuries. There have been several attempts to introduce them into use of late years in the United States, but it is hardly worth while here to notice any of the proposals, as they have not come into general use. With pure nitro-glycerine, no tamping is needed but water; therefore nitro-glycerine, having greater specific gravity than water and no affinity for it, is an especially suitable agent for subaqueous blasting, where it can simply be poured down into the holes through a tube and funnel.* Fig. 24 shows a charge of nitro-glycerine with water-tamping and tape-fuse and exploder. Where the rock is split or seamy, nitro-glycerine must be encased in some substance, say tin cases, and this, it is said, lessens its explosive force by preventing close contact. Where the rock is firm, it can be poured directly into the hole. In this respect, dynamite has a great advantage over nitro-glycerine in that it can be charged in roof-holes and in seamy rock, there being no danger of running out, leakage, etc. In charging No. 1 dynamite, it was formerly thought that no tamping would be required, but the general experience of blasters has led to the practice of tamping the holes solidly to the lip with clay. The fact that tamping is not so essential with the high explosives as with the lower ones, should not be taken as proof of any radical difference in the theory of tamping being required in both cases. The law of tamping is the same, for in both the disruption is effected by the sudden liberation of expansive gas; only in the one case the liberation of gas is instantaneous, and in the other gradual. In either case, strong confinement promotes the effect. A wooden rammer should be used with dynamite.

FIG. 24.

That vacancies about a charge do have a practical effect in reducing the force of explosion of nitro-glycerine or of its compounds is shown by the following record. The experiments were made at the works of the Atlantic Giant Powder Company with the mortar described p. 77. The charge used with each shot was one-quarter ounce of No. 2 dynamite; and the object of the experiments was to see whether a small space left between the ball and the bottom of the bore would have any appreciable effect in lessening the distance the ball was thrown.

* There was shown in the British section, Paris Exposition of 1878, a patented water cartridge tamping, by MacNab, claimed to yield superior results in coal, etc., with black powder. (See also MacNab's Patent for wedging charge, *post* 287.)

	Shot Raised.	Thrown.	Loss.
No. 1	.00 inch	630 feet	00 feet.
" 2	$\frac{1}{20}$ "	579 "	51 "
" 3	$\frac{2}{20}$ "	550 "	80 "
" 4	$\frac{4}{20}$ "	490 "	140 "
" 5	$\frac{8}{20}$ "	440 "	190 "
" 6	$\frac{12}{20}$ "	400 "	230 "
" 7	$\frac{16}{20}$ "	350 "	280 "

This effectually shows that the hollow space theory of old has no application to the high explosives. The same conclusion has been reached in General Abbot's recent researches, referred to in the footnote *ante*, p. 98.

Fig. 25 shows a charge of several dynamite cartridges with tape fuse and exploder inserted in the last cartridge, and the whole tamped with clay.

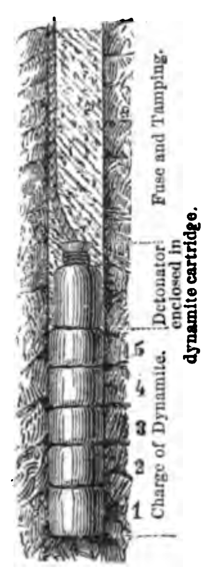


FIG. 25.

FIG. 26.

Should the supply of exploders run out, dynamite may be exploded with a small charge of gunpowder placed above it in which a fuse is inserted as in ordinary blasting with black powder. In this case, the tamping should be firmly rammed, so that the black powder may explode under as great pressure as possible. Either dynamite or nitro-glycerine fired with a gunpowder fuse is very uncertain in action. Sometimes it is exploded and sometimes not, and even when exploded its force is much less than when the fulminate is used. Hill* says that many experiments have been made at the U. S. Torpedo Station at Newport, R. I., with gunpowder fuses, but no satisfactory or concordant results obtained.

(N. B. This should be taken as to No. 1; it is questionable whether No. 2 dynamite can be detonated as well at least even as No. 1, by the adjoining explosion of black powder.)

With nitro-glycerine compounds containing soluble and especially deliquescent salts, it is best to enclose them in water-tight cartridges in wet holes, and tamp with clay. (No. 2 dynamite, made with nitrate of potash, is said to be practically unaffected by immersion in water.)† As to the use of pure nitro-glycerine (for its characteristics, see p. 65), it was preferred as an explosive agent at the Hoosac Tunnel in the heading, and, where a high explosive is desired, it probably is the cheapest material to use in cases where the works in which the explosive is to be applied are of such magnitude as to require a long period for their completion. In these cases—as at Hoosac, for instance—it has been found economical to manufacture the nitro-glycerine on the spot; this has also been done at other points, where the works were of much less importance. In cases like the above, systems of careful supervision can be established, and the liquid explosive applied with economy; for properly and intelligently used, it can with certainty be said to be a safer compound to handle than ordinary black blasting powder. But in general, owing to its undoubted greater safety, more general application, and easy handling, dynamite seems, both in Europe and in this country, to be preferred. By "more general application" is meant, that, in nine cases out of ten, dynamite will be used with equal effect to the pure nitro-glycerine. It may seem paradoxical to say that seventy-five per cent of a substance is equal to one hundred per cent, but we are not speaking now theoretically, but of the practical application of these explosives, and herein must be taken into account the waste that ensues from the use of a liquid, the fact that it cannot be used or tamped in top holes slanting downward, or in seamy rock, unless enclosed in tin or other stiff cartridges,

* On Explosives, p. 33.

† Whether compounds of nitro-glycerine with soluble salts (No. 2 dynamite, Lithofracteur, Rend-Rock, Vulcan Powder, etc., etc.) are affected by being charged in wet holes at a temperature of 30° F. or under, has not yet been positively decided. Conflicting results have been obtained, possibly owing to differences in the length of time the charges may have been exposed to the action of the water. The low temperature would tend to weaken the nitro-glycerine.

which then prevent close contact, as noted above, and thereby insure a waste of force. Moreover, nitro-glycerine in its pure state is too quick and strong an explosive to be used to best advantage except in deep holes in the strongest rock, when its full strength can be utilized; and even in deep heading holes, it has been abundantly shown, in the construction of the Musconetcong and the Sutro Tunnels, that No. 1 dynamite is fully equal to the task of cleanly bringing out 8, 10, 12, and 13 foot cuts at a shot.

In bottom and side work in tunneling, No. 1 dynamite is too strong to be economically used, and lower grades will generally be found cheaper, as it pays better, in cases where the line of the hole is parallel or approximately so to the face of the rock, to distribute the force throughout its length, as the line of least resistance in these cases is a continuous one, or, in fact, becomes a plane.

In the heading, on the contrary, where, as is the practice abroad, perpendicular holes to the face are used, or, as in this country, the deep-cut system, the line of least resistance is a straight line from the charge or from the apex of the cut to the surface, and therefore the full strength of the charge is required at the apex, and there the strongest explosive is the best. (For a discussion of the intrinsic characteristics of dynamite, see p. 70.)

The Drill.

Figs. 17(*a*) and 17(*b*) (p. 108) show the earliest form of bits used in pointing drills. Fig. 27 shows another that has been used in Germany, and which, since the rise of machine-drills, has been applied as the best suited for the wear and tear caused by their rapid and heavy blows.

Figs. 28(*a*) and 28(*b*) show the edges of two other forms of bits tried, in each of which there is a transverse edge and a slight side one. Figs. 29 to 36 inclusive show others.

Fig. 27.

Fig. 28(*a*).

Fig. 28(*b*).

Fig. 29.

Fig. 30.

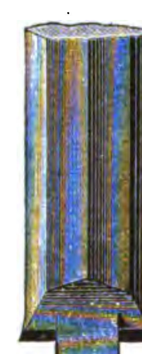


Fig. 31.

Fig. 32.

Fig. 33.

Fig. 34.

Fig. 35.

Fig. 36.

Fig. 37.

Fig. 38.

Figs. 37 and 38 show the curved chisel-bit in ordinary use, which has been proved, by the experience of hundreds of years, to be the best for ordinary hand-drilling; let us consider why it is necessarily so.

Take a purely straight-edge bit, as shown in Fig. 41, and consider that in Fig. 39 the

Fig. 39.

Fig. 40.

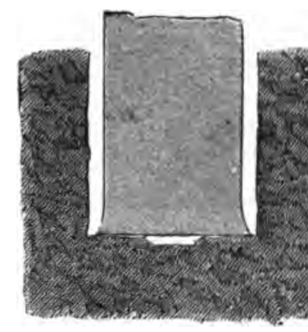


Fig. 41.

white lines show successive cuts made by it in turning. Theoretically, the drill is turned on a centre in the middle of the hole; practically, the successive cuts cross each other a little as shown in Fig. 40, the hole being necessarily broken a little wider in diameter than the extreme

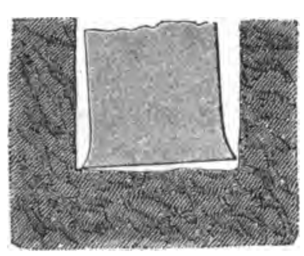


Fig. 42.

Fig. 43.

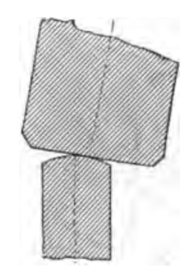


Fig. 44.

width of the bit. In either case, we see how vastly more work the drill has to do at the circumference of the circle than at the centre, and therefore a straight-edged drill, as in Fig. 41, will soon be worn more at the ends (Fig. 43) than the middle of the edge, and it will

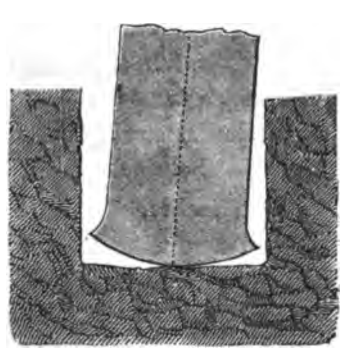


Fig. 45.

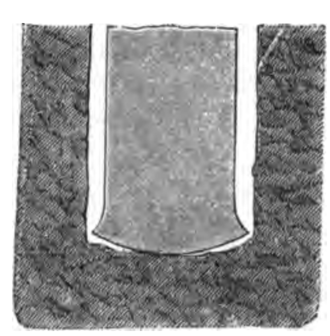


Fig. 46.

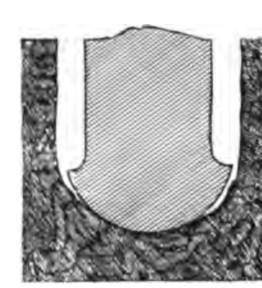


Fig. 47.

naturally approximate to the curved edge, which, if originally adopted, therefore gives the most uniform wear. There are also considerations affecting the form of the edge. Theoretically speaking, the drill is supposed to be held always vertically in the hole, and the blow is further supposed to be given directly on the head of the drill, the axis of the hammer at the

moment of impact being perpendicular to the axis of the drill. In practice, however, the drill may often be held at a slight angle, as in Fig. 42, and the blow is besides often given inaxially, as in Fig. 44; these results also tend to a rounding of the straight edge, if used as in Fig. 42. Fig. 45 shows that with a rounded edge an inaxial blow will take effect nevertheless on the body and not the end of the edge; in other words, the more the edge be curved, the more nearly will inaxial blows take effect at the centre, and the practical mean to be reached is the one somewhere here between a flat edge and a diamond point; the amount of curvature, as well as the tempering of the steel, must be adapted in each case to the material to be drilled. Thus in hard ground a flatter curve and in easier ground a sharper curve will be found best, varying perhaps from Fig. 46 to Fig. 47.

It has, in fact, been found by experience, that,

(*a*) Straight-edged drills blunt quickly at the corners.

(*b*) Edges with too sharp a curve blunt first at the centre.

(*c*) Edges with light curves are best adapted to hard, and those with sharp curves to easier ground.

(*d*) The proportion of the extreme width of the bit to the diameter of the drill may vary from 7 : 6 to 4 : 3. In easy rock, the shoulder of the edge need not be so great as in hard, as the ends are not subjected to so great a strain.

(*e*) The angle of the two faces may be put at the highest for strong drills in hard

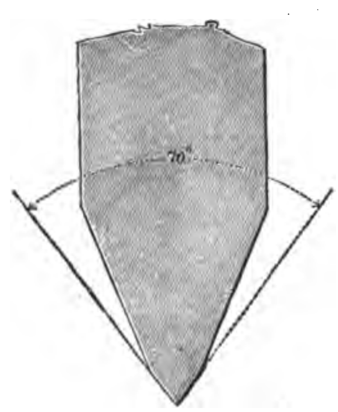


Fig. 48.

Fig. 49.

Fig. 50.

rock, at say 70°, as in Fig. 48. In hard ground, however, the drill should be rather rounded, as in Fig. 49, to give support to the point, and in very easy material (hard earth, etc.) where a crushing rather than a cutting edge is needed, it is well to slightly blunt the edge as in Fig. 50.

Expanding Borers.

Many types of borers have been tried for enlarging a drill-hole at its bottom. The manifest advantage of an enlarged chamber at the foot of the drill-hole is, that the charge can thus be made heaviest at the point where the resistance is strongest. An attempt to thus enlarge holes driven in limestone was made at a quarry near Sistiana by pouring nitric acid into the hole to dissolve out a chamber at the bottom. The stone quarried at Sistiana was used for the harbor at Trieste. This plan never came into general application: in any event, it would only apply to calcareous rocks.

Fig. 51 shows another cutter somewhat similar in principle, but without the curved edge. It was patented in England, September 15th, 1853, by Henry Kraut. The part *b b*

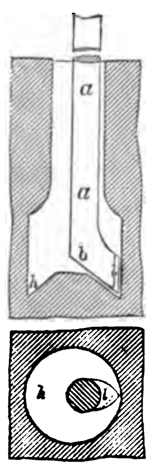


FIG. 51.

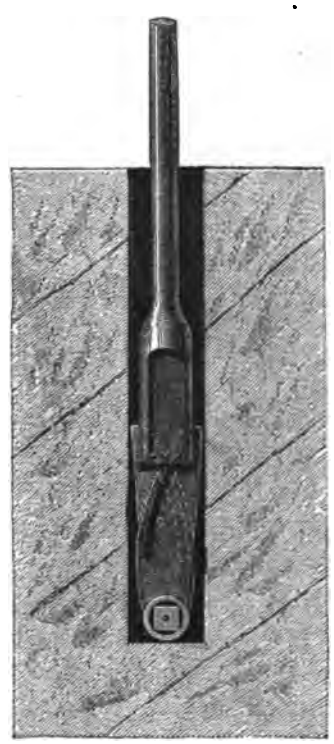


FIG. 52.

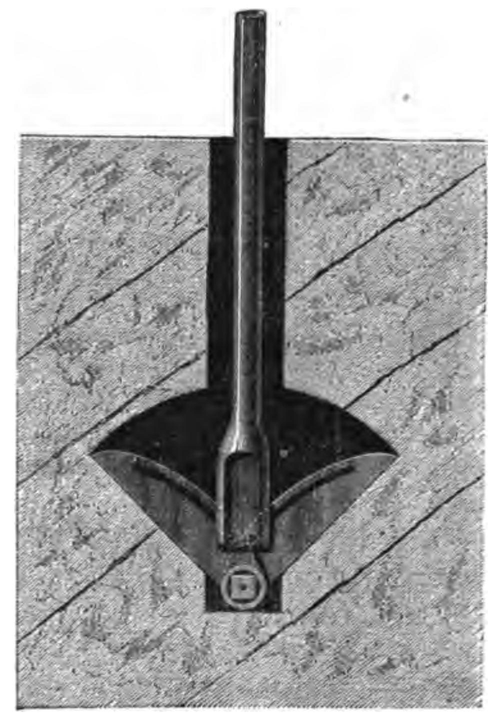


FIG. 53.

is of solid steel and welded to the iron *a*, and it is represented as arrived at the bottom of the chamber *h*.*

Figs. 52 and 53 are taken from Ržiha;† they represent what is called the "shear-borer." This drill is described by Schoen‡ also. As will be seen from the figures, the drill is provided with expanding blades, which open when the drill is turned one way, and close when it is reversed and drawn out of the hole. When closed, the blades remain in that position, and are opened automatically when the drill is struck against the bottom of the hole.

THE HAMMER.

As to the hammer, there have been long-standing controversies between the different races of miners with reference to the use of light hammers of from three to five pounds, or the heavy—say nine-pound ones. The Piedmontese miners are famous for their work with the latter in eight-hour shifts. Of course, in much one-hand drilling, especially upward work, the light hammers must be used.

There has also been much discussion in Europe as to the relative advantages of single-hand or two-hand drilling. One of the most complete expositions of the subject ever written will be found in the "Revue Universelle des Mines" (Liège, Mai et Juin, 1876), in an article by M. Jules Havrez, on the "Creusement des Trous de Mine." In France and Bel-

* "Civil Engineers' and Architects' Journal," vol. xvii., p. 335.
† "Lehrbuch der Gesammten Tunnelbaukunst," vol. i., p. 97.
‡ "Der Tunnelbau," p. 40.

gium, the two systems are known as "La petite Batte" and "La grosse Batte." In the former, small holes, of from 25 to 30 mm. (1 to 1·2 inches), are drilled by a miner, who holds the drill in one hand and strikes with the other; in the "Grosse Batte" system, holes of from 30 to 40 mm. (1·2 to 1·6 inches) are drilled, one miner turning the drill and the other striking. M. Havrez's discussion of this question is exhaustive, and is chiefly directed toward an inquiry as to which mode of drilling is most advantageous in the rocks encountered in coal-mining, and his final conclusions are as follows:

"We can therefore conclude, as to these two modes of drilling, that, in point of economy of time and money, one-hand drilling is from 30 per cent in soft schists to 20 per cent in soft sandstones cheaper than two-hand drilling. In very hard rocks, on the other hand, a saving in direct outlay of about 15 per cent can be effected by two-hand drilling over one-hand drilling; this is especially the case with ten-hour instead of eight-hour shifts. This saving is, however, made in cost alone, as one-hand drilling gives the more rapid advance, and should be used even in the harder rocks, where speed is an especial object."

In tunnel-headings, however, in America, we know that the rule is in favor of two-hand drilling in general; often, indeed, two hammers on one drill are used. As to the remaining tools used in blasting, the rammer, swab-stick, picker, etc., their proper use and application, is a simple matter, and their form, etc., may be best studied in the mines.

The Principles of Blasting.

Now, what is blasting? It may be defined to be the rending or tearing apart of any solid body, by the pressure or shock exerted upon it from the sudden development of gas of high tension evolved on the ignition of some explosive compound placed contiguous to it. As the drilling of the holes may be said to be the dearest part of blasting, it follows that great care should be taken in setting each hole in such a position and in drilling it of such width and depth as to insure the greatest effect at the least cost. When we recall the many circumstances that may influence the effect of a shot, it is evident that the proper setting of a hole is a matter rather of judgment based on experience than one to be decided by empirical rules, for even were a set of rules deduced from experiments in one material, they would only apply, under similar circumstances, in the same material. The effect of a shot may be influenced, among other considerations, by:

(*a*) The shape in which the rock is presented, the size and number of the open faces, the shape of the piece it is desired to take out, if that is an object, and, of course, primarily, the size of the cross-section of the face, if it is heading work.

(*b*) The texture of the rock, whether it is hard or easy, firm or loose, whether it is brittle or tough; thus experience gained in blasting close-grained, hard granite, trap, gneiss, etc., would not apply to limestone, sandstone, slate, etc., etc.

(*c*) The structure of the rock, as to whether it is laminated, stratified, or fissured; upon its cleavage, etc., and upon whether it is massive or broken, etc.

(*d*) The elasticity of the rock.

(*e*) The explosive used.

(*f*) Whether the hole is to act alone or simultaneously with or following others; in the case of simultaneous firing, the question arises of how the waves of oscillation will best act in concert.

(*g*) The character of the fuse and tamping.

And now, supposing a shot is to be placed in any position whatever, we have seen that its *action* will be in the line of least resistance with the lower explosives, and its *greatest effect* will also be in the direction of that line with the higher ones (as to the difference between

the two terms, see p. 97). Let us consider the line of least resistance in black powder. We must assume that, on ignition, the gases developed act primarily radially, that therefore the tension of the gas extends from the point of ignition (which must be assumed to be in the centre of the charge) in all directions, and that, according to the location of the charge and of the number and relation of the open faces, an undulation in the rock is produced, which, when the limit of elasticity is passed, will cause the splitting and tearing apart of the rock; and as the force developed will naturally find its vent by the shortest road, the distance between the charge and the nearest external point is called the line of least resistance.

(In a perfectly homogeneous material, a regular funnel or crater would be formed, but this is, of course, only approximately attained. In actual practice, an irregular separation of the rock is effected.)

We accordingly have the following general rules:

1. The hole should not be located in the line of least resistance, otherwise the tamping would simply be blown out. (Be it remembered this discussion is as to black powder, not nitro-glycerine.)

2. Experience has established the average ratio between the depth of hole and the length of the line of least resistance to be as four to three, or the length of the line of least resistance will be three quarters of the depth of the hole, and experience has further shown that the charge of black powder should be, on the average, about one third ($\frac{1}{3}$) of the depth of the hole, the varying limits being $0 \cdot 29$ to $0 \cdot 45$.

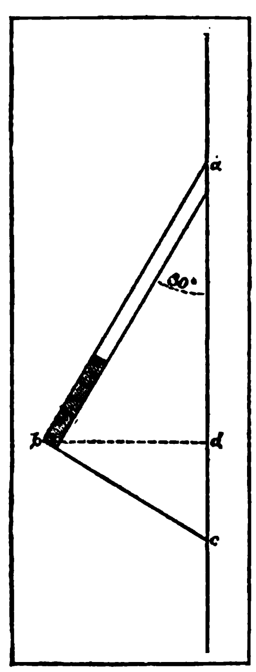


FIG. 54.

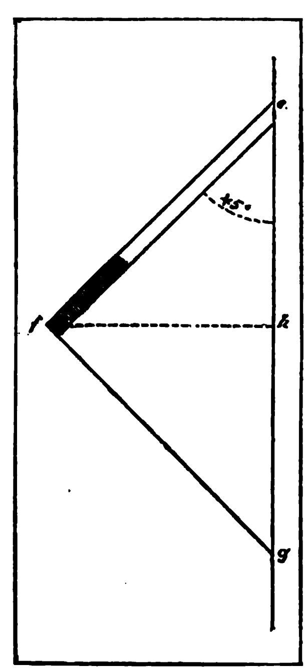


FIG. 55.

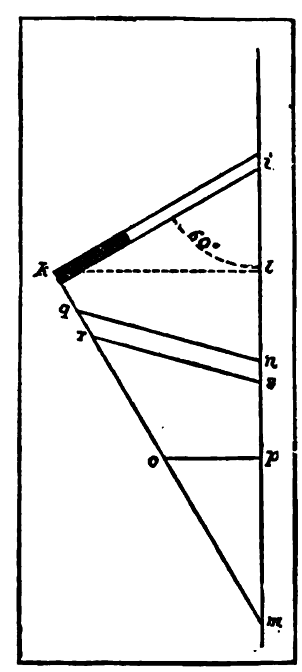


FIG. 56.

If in a massive rock not fissured, presenting a vertical face, we bore a hole *a b*, Fig. 54, we may in general expect a break in the general direction *a b c*, which can be measured by the line *b c* drawn *perpendicular* to *a b*. It is, moreover, proved by general experience that the sphere of rupture determined by *b c* will seldom be larger than the depth *a b* of the hole, and it would probably be equal to *a b* only in very easy material, when *a b* is set at

an angle of less than 45° with the face $a\ c$. If we bore the hole $e\ f$ (Fig. 55) on an angle of 45°, we will have for the length $f\ h$ of the line of least resistance the expression,

$$f\ h = e\ f\ cos\ 45° = e\ f\ 0 \cdot 707,$$

by which the greatest possible value ($\frac{3}{4}$) is reached.

While in Fig. 54, on account of the assumed firmness, structure, coherence, etc., of the rock, the line of least resistance formed an angle less than 45° with the face, there may be other cases (Fig. 56) where the hole should be set at a greater angle, say even 60°. In this instance, if the face $i\ m$ be all firm rock, it is not probable that the volume $i\ k\ m$ would be detached, but in general the wedge $i\ k\ g\ n$ would be ejected. But say $o\ p$ represents a fissure

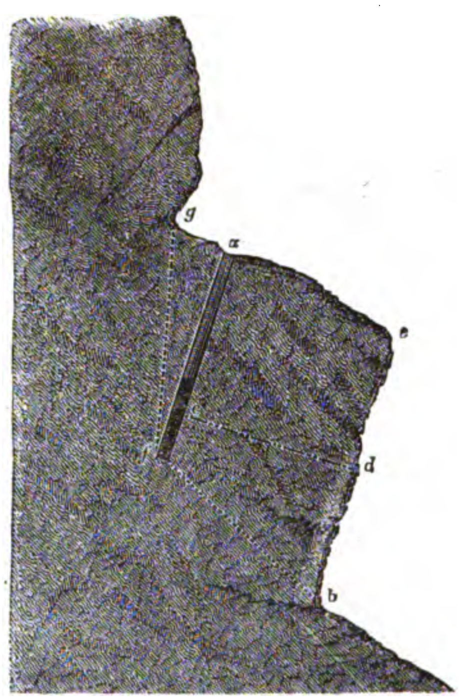


Fig. 57.

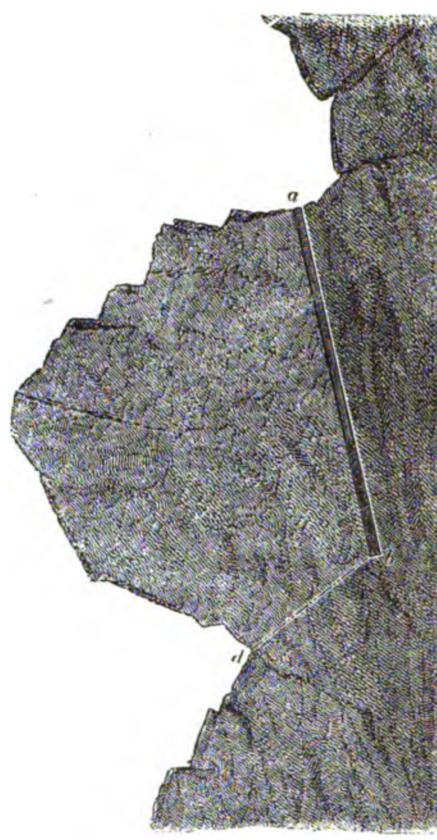


Fig. 58.

or holing, or perhaps an open face produced by a former shot, we may then, irrespective of the line of least resistance $k\ l$, assume that, under favorable circumstances, the section $i\ k\ o\ p$ would be thrown, provided $k\ o$ be not larger than the depth $i\ k$ of the hole. From these considerations, we may deduce that,

3. Holes ought in general to be bored at or under an angle of 45°; a larger angle, increasing to as much as 90°, is advisable when open faces (as $r\ s$ in Fig. 56) occur, and a smaller angle (Fig. 54) is advisable when the texture and structure of the rock necessitate assuming the line of least resistance as less than three quarters of the depth of the hole. Further, as the mass thrown breaks in the general direction of the line of least resistance, and as, in fact,

this line lies in the mass ejected, or. in the extreme case of an angle of 90°, bounds the ejected mass, we must carefully observe,

4. The external shape of the rock, in order to reach a maximum effect.

(*a*) If *a f* (Fig. 57) represent a hole parallel to the open face *e b*, the line of least resistance *e d* will indicate the general throw of the shot. It will not be necessary to bore the hole *a f* to the total depth *e b*, for it may be assumed in most cases that a curve will be formed in the general direction *f b*. Similarly, we may presume, under favorable circumstances, that the blast will also break in the direction *f g*. The shot *a f* would have been set very favorably if there ran from *g* a crack about parallel to the hole, and from *b* another perpendicular to it.

(*b*) If, as in Fig. 58, we assume an existing lower cut in the cavity at *d*, we might then take *b d* as the line of least resistance, and to obtain a maximum would extend it to three quarters of the depth of the hole *i. e.*, set the hole still more obliquely than shown in the figure, for in this case the deeper the hole, and the more the rock to be blasted bulges, the greater will be *the result of the shot.*

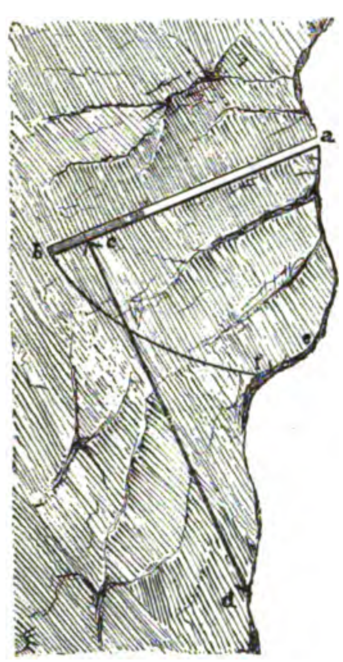


FIG. 59.

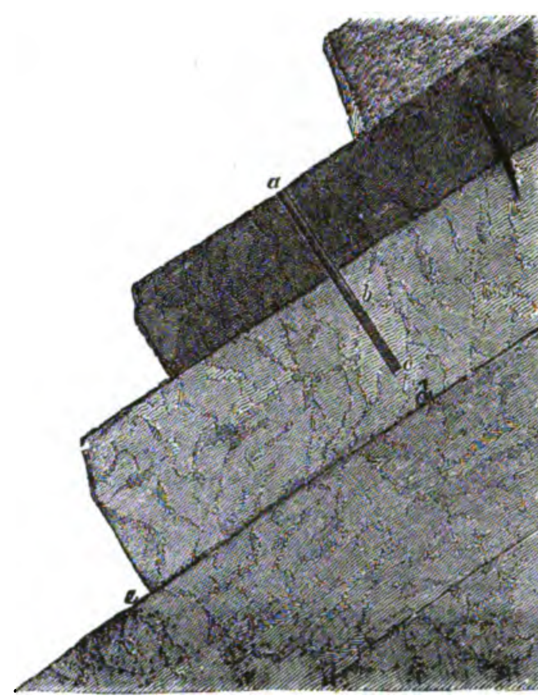


FIG. 60.

(*c*) The shot *a b* (Fig. 59) may be considered as an *unfavorable* case, provided the hole cannot be set *above a*, for now the shot can only break approximately in the lines *a b f*, as, if the line of least resistance were sought in a line drawn perpendicular to the hole, it would be nearly vertical; further, the shot cannot act as far as *d* (supposing the rock to be solid), for the distance *c d is longer than the hole a b.* A hole set more obliquely at *a* and bored to a greater depth would be also unfavorable, for the mass of the portion *f d* would be too thick, and the rock being hollowed at *f*, a line drawn from *f* perpendicular to the hole would then represent the line of least resistance, and the shot would probably act only to the point *f*, leaving *f d* standing. Another very important rule supplementing the preceding one is,

5. Clefts and fissures and lines of stratification in the rock must be carefully used to advantage.

Such separation faces always represent in a minor sense open or clear faces, and where they exist back of or beyond the hole, we must presume that the shot will act not only outward but inward, and lines of least resistance will then have to be considered both ways; Fig. 60 may be taken as an example. The shot will probably act beyond the bottom *c* of the hole, and the distance *c d* to the next stratification-bed may be taken as the first line of least resistance, and an effect thence toward the exterior (perpendicular to *a c*) may be taken as the second. What in such a case may be estimated as the extreme limit of *c d* and *d e* would have to be found by trials. In these cases, of course, the distance *d e* will be over the average rule of three quarters *a c*.

When irregular clefts and cross-fissures occur, the question becomes more complicated, and the effect is generally directed to obtaining the largest possible wedge.

In general, we may say, as to blasting in regularly stratified rock, that,

6. In regular seams, the shots should be set perpendicular to the face of the seam.

7. The portion of the hole holding the powder (*b c*, Fig. 60) should be located within the whole rock. This rule, of course, only holds in rock where the strata are thicker than the depth of the powder-charge in the hole. If the charge intersect a stratification-bed, there will, in general, be a waste of force. Therefore, a short-fissured rock (*i. e.*, one naturally broken by short clefts, etc.), or one much laminated, though it gives more faces for the powder to act on again, is ultimately less favorable material, in many cases, than more solid material; therefore,

8. Short-fissured, laminated, or slaty rock should not be drilled, if possible, in the direction of the laminæ, but, according to circumstances, in an oblique or normal direction to them.

Should a hole be located in a rock divided into thin laminæ, the effect of the shot would possibly only extend to the adjoining beds, and a small wedge might be thrown out; but if the shot be set in a line perpendicular or oblique to the beds, though undoubtedly the charge would be cut by the layers, still a greater effect would probably be obtained. As we shall see (p. 117) that the volume of the blasted body, on an average, is as the cube of the depth of the hole, it is a self-evident deduction that costly preliminary shallow hole-work should be avoided as much as possible, and the main masses be thrown by deep-set shots.

Therefore, not only should

9. Each shot be set so as to clear a bearing for following shots, but also

10. The proper volume should be blasted away.

(*a*) The first shot at the face of a drift is of course theoretically, and generally practically, the one most unfavorably located.

(*b*) If the strata dip toward the face, hence toward the miner, the breaking-in is started at the roof (Fig. 61). This case is the most favorable one, as the miner may then easily cut the seams perpendicularly to the strata, as in Fig. 60, and the drilling is downward.

(*c*) If the strata dip from the face (Fig. 62), the breaking-in must be started at the bottom, and succeeding shots are drilled either under an angle steeper than the dip of the strata, or, if the strata be thick, the shots may be drilled parallel to the stratification-bed; and in this case, rule No. 8 will, of course, not apply.

(*d*) Cases may occur where the breaking-in may be located advantageously at the middle of the face.

(*e*) If the stratification be vertical, and parallel to the line of the drift, the breaking-in is generally made at the side.

11. *Short-fissured or very tough rock requires shallow holes; coarse-fissured, moderately tough rock takes holes of average depth; and brittle and solid rock works well with deep holes. In tough rock wide holes and in brittle rock narrow holes are the more economical.*

It should here be noted that *firm*, *brittle* rock may be distinguished by the rebound of the hammer; it drills hard, but breaks easily.

Examples are: Trap, granite, gneiss, syenite, etc.

Firm, *tough* rock does not cause the hammer to rebound so violently, leaves a white streak when scratched with steel, drills easy, but breaks hard.

Examples are: Limestone, porphyry, quartzose lodes, etc.

12. In driving a heading, particular care should be taken that unnecessary cost in flush-

FIG. 61.

FIG. 62.

ing the clear profile does not arise. Large protuberances and cavities must be avoided, and particular care in this respect should be paid, in tunneling, in taking out the bottom or bench, that there be not a large amount of trimming left to be subsequently done in clearing the normal profile, for such work not only is very tedious, delaying the work, but is costly. For this reason, holes located near the sides or roof should receive especial care.

DISCUSSION OF VOLUMES THROWN IN BLASTING.

When a hole is bored in a vertical face of a solid rock in the direction of the line $a\ b$ (Fig. 63) and fired, if the tamping is not well rammed, the shot will probably simply blow out or only loosen a comparatively small portion of rock. If the tamping be well rammed, and the rock good, favorable material, a conical body—the so-called *crater or funnel*—will be thrown out; for which, with black powder, the radius of blasting, $b\ c = b\ d$, may be assumed, for discussion, to be about equal to $a\ b$; we will call $a\ b = A =$ line of least resistance. In this blast, therefore, a conical mass of rock would be thrown out, the volume of which, V, may be approximately expressed by $V = \frac{t^3 \pi}{3} = 1 \cdot 05\ t^3$. HENCE, THE VOLUME OF THE MASS BLASTED IS AS THE CUBE OF THE LINE OF LEAST RESISTANCE.

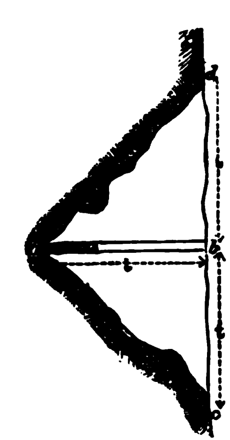


FIG. 63.

This formula, however, applies merely to a plain, open face in good rock; considering still that we are treating of unfissured average ground, let us then consider some of the cases where two or more faces may be acted on by the charge. Take a cube freely suspended in the air, with a charge of powder at its centre. On firing (in a homogeneous material of course), the gases

developed meet with equal resistance in the direction of the six faces, and theoretically there will be six craters, with the corresponding corners also broken.

A short computation will show how the total volume of broken ground increases with the number of open faces, in a ratio that is rather more favorable than a direct proportion. This, though only a mere theoretical view, is of value as clearly placing the advantage of setting holes to act in concert by opening as many faces as possible.

Fig. 64 shows the cube above suggested freely suspended and a charge located at its centre. We have for the volume of the crater at one face, $V = 1 \cdot 05\ t^3$; for the six faces of the cube there must then be $6 (1 \cdot 05\ t^3)$ or $6\ V = 6 \cdot 3\ t^3$. There are besides the eight corner-pieces, which remain after deducting the volume of the cones from that of the cube (c). As the volume of c is of course $= (2\ t)^3 = 8\ t^3$, the total cubic contents of the corners must be $8\ t^3 - 6 \cdot 3\ t^3 = 1 \cdot 7\ t^3$; hence a single corner $e = 0 \cdot 212\ t^3$.

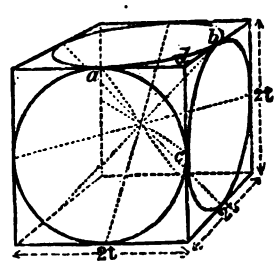


FIG. 64.

Now, take a solid mass (Fig. 65), with only two open square faces $d\ e\ f\ g$ and $d\ e\ i\ h$, and consider each side $= 2\ t$.

On firing a charge located equidistant from these two faces, there will theoretically result two craters $2\ V = 2\ (1 \cdot 05\ t^3) = 2 \cdot 1\ t^3$.

But it may be assumed also that portions have been detached from the corners at d and e, say in each case one half the corner. We may then theoretically consider that, as to a solid with two open faces, the volume of the blasted mass may amount to

$$2\ V + 2 \frac{e}{2} = 2 \cdot 1\ t^3 + 0 \cdot 212\ t^3 = \text{say}\ 2 \cdot 3\ t^3.$$

If we continue the computation similarly as to solids with three, four, to six open faces, we will obtain the following tabular arrangement:

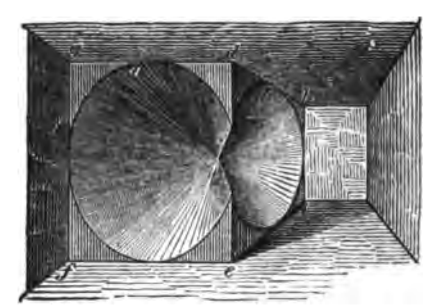


FIG. 65.

TABLE 14.

THEORETICAL VOLUMES IN BLASTING WITH BLACK POWDER.

Number of open Faces.	Volumes expressed in Terms of the Line of least Resistance t.			Volumes expressed in Terms of the Depth of Bore-hole l.
	Cone $v = 1 \cdot 05\ t^3$.	Corner-piece $e = 0 \cdot 212\ t^3$.	Total in round Numbers.	
1	1 V	....	$1 \cdot 05\ t^3$	$0 \cdot 37\ l^3$
2	2 V	$\frac{2}{2}\ e$	$2 \cdot 3\ t^3$	$0 \cdot 83\ l^3$
3	3 V	$(1 + \frac{3}{2})\ e$	$3 \cdot 7\ t^3$	$1 \cdot 32\ l^3$
4	4 V	$(2 + \frac{4}{2})\ e$	$5 \cdot 1\ t^3$	$1 \cdot 83\ l^3$
5	5 V	$(4 + \frac{4}{2})\ e$	$6 \cdot 5\ t^3$	$2 \cdot 33\ l^3$
6	6 V	8 e	$8 \cdot 0\ t^3$	$2 \cdot 86\ l^3$

If in the above table, we make the volume blasted at one face equal to unity, and suppose the line of least resistance t to remain the same, we will find that the volumes of the several cuts for 1, 2, 3, 4, 5, 6 open faces are to each other approximately as $1 : 2 \cdot 2 : 3 \cdot 5 : 4 \cdot 9 : 6 \cdot 2 : 7 \cdot 6$, hence *the ratio of gain in using open faces is greater than a direct one.*

Now, we have here seen the theoretical volumes thrown, where cones are blown by holes

set perpendicular to the face, and the calculations have been made in respect to holes set in this line, but this line $a\,b = t$ (Fig. 66) is the line of least resistance, where there is but one face, and we have seen (p. 119) that bore-holes should not be located in the line of least resistance (with black powder). But (p. 120) we have seen further that a hole set at an angle of 45° (Figs. 67 and 55) is the case midway between the extremes of very tough and loose rock shown in Figs. 54 and 56, and that, with an angle of 45°, the line of least resistance $= \frac{3}{4}$ of the depth of the hole, so that the same volume will apply, as it is the same figure, with the bore-hole changed in position. In this case, the volume of the cone blasted $V = 1 \cdot 05\, t^3$ may be expressed in terms of the depth $a\,c = l$ of the bore. We will thus have $V = 0 \cdot 37\, l^3$, since $l = 1 \cdot 3\, t$ and $t = 0 \cdot 71\, l$. This expression, however, it must be remembered, is merely a theoretical one designed to formulate and concisely show the essential principles of blasting. Of course, no approximate single formula could be devised that would apply to the varying positions which occur in blasting and the varying materials met with. Schoen* has, however, taken $V = m\, l^3$ as a general formula, in which the coefficient m is to be varied according to the material, and he presents the following values, as deduced from various trials, for m.

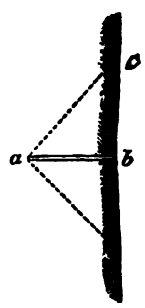


FIG 66.

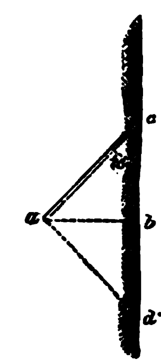


FIG. 67.

Values of the coefficient m in the formula $V = m\, l^3$, for different rocks:

Jurassic Rock (firm)	$m = 0 \cdot 38$	$m = 0 \cdot 4$	On an average, $m = 0 \cdot 65$.
Gneiss	$m = 0 \cdot 39$		
Calcareous Slate	$m = 0 \cdot 41$		
Dolomite	$m = 0 \cdot 41$		
Galena	$m = 0 \cdot 42$		
Quartz	$m = 0 \cdot 42$		
Trap	$m = 0 \cdot 77$	$m = 0 \cdot 9$	
Granite	$m = 0 \cdot 85$		
Jura Limestone	$m = 0 \cdot 85$		
Calcite (calcspar)	$m = 0 \cdot 96$		
Mica-schist	$m = 1 \cdot 02$		

In this table, which must be accepted merely on approximation (Schoen says of it, "welche freilich nicht auf Vollständigkeit Anspruch machen kann"), m amounts to $0 \cdot 4$ for very tough rock, and to $0 \cdot 9$ for more brittle rock with one open face.

As to the width and depth of holes, they must vary with the rock and location—*i. e.*, whether in open cut, small or large heading, bottom holes, block holes, etc. The distance apart of the holes in a face should be so proportioned that the burden may be divided, and that, after the blast, the face rock left standing may be loosened with ease by picking and wedging.

Theoretically, the number and depth of holes required to break a face with no loss of force may thus be approximately estimated. Practically, however, the location, depth, etc., of the holes required in a given rock become rather a matter of instinct to an intelligent blaster, after due experience gained in different kinds of rock; but the foregoing general

* "Der Tunnelbau," p. 91.

discussion may perhaps be of value in arriving at a correct judgment by supplementing practical experience in the use of black powder with theoretical computation.

In this connection, the following extract from Schoen is given ("Der Tunnelbau" (1874), p. 103, *et seq.*) The author of this work has had no opportunity of verifying the results set forth, nor do the tables in all points agree with the author's personal experience. They are of interest, however, as being advanced by Schoen, and they are said by him to be based on and drawn from actual practice in Europe.

The first effort of the miner in a heading should be directed toward loosening the coherence of the rock, as the latter is of course much greater in a small heading than in open work. The difficulty of working may be said to be four to five times greater in the former than in the latter case; indeed, it may safely be assumed as a rule that *the expenditure of power and money increases in the inverse ratio of the squares of the areas to be excavated.* The first loosening of the coherence of the rock is to be effected obviously at the point where the breaking-in can be performed with the least difficulty; hence at places where clefts, fissures, soft intermediate strata, and the like occur.

In the following table is given the number of cubic metres of rock which a miner can blast out in an eight-hour shift in narrow areas, such as are given by, say, headings or shafts of 5 square metres (about 6 square yards) clear area:

	CUBIC METRES.	
Gneiss	0·044 0·075	Average value: 0·0692, or about 0·07, in compact and very compact rock; or, say, in rock blasted with difficulty.
Quartz	0·046	
Granulite	0·066	
Granite	0·079	
Syenite	0·076	
Porphyry	0·076	
Heavy Spar (baryta)	0·076	
Galena	0·085	
Calcareous Spar	0·107	Average value: 0·164 in easier and less compact rock; or, say, in rock easily blasted.
Limestone (Jurassic)	0·125	
Sandstone (red, blue)	0·126	
Dolomite	0·136	
Graywacke	(0·064)—0·142	
Gypsum	0·222	
Calcareous Slate	0·224	
Clay Slate	0·232	
Total average	0·114 cubic metres.	

These coefficients show very well the ratio of extraction in rocks of different hardness, and it will be seen that a miner's work in clay slate, calcareous slate, and gypsum is indicated as being nearly five times greater than in gneiss. The numbers may also serve proportionally to approximately determine the amount of a miner's work in cross-sections larger than five square metres, *as for the same kinds of rock the amount of work performed are to each other as the square roots of the areas of the cross-sections.* For instance, in excavating the full cross-section of a double-track tunnel, the area of which amounts to 42 square metres, a miner will extract during eight hours of work:

In very compact rock in which for a cross-section of 5 square metres the average work performed by one man during eight hours is 0·07 cubic metres:

$$\left.\begin{matrix}\sqrt{5}\,\square & : & \sqrt{42}\,\square^m \\ 2\cdot 2 & : & 6\cdot 4\end{matrix}\right\} :: 0\cdot 07 : x$$

$x = 0\cdot 2$ cubic metres extracted = amount of material removed from the above cross-section of 42 square metres.

And

in a rock which can be easily quarried and blasted:

$$\sqrt{5}\,\square : \sqrt{42}\,\square^m :: 0\cdot 164 : x$$

$x = 0\cdot 48$ cubic metres extracted = amount corresponding to the area of 42 square metres.

These values of x agree very well with the results obtained in practice (according to Schoen).

Estimate of the Cost of Extraction.

The following tabular arrangement contains data showing the work performed by a miner in six different kinds of rock. The table serves also to determine the time required for extracting one cubic metre of material from the full area of a tunnel, and it is based on the personal experience of J. G. Schoen and other engineers in Europe:

TABLE 15.

KIND OF ROCK.	CLASS.	(a) Amount of material in cubic metres that a miner can extract in eight-hour shifts in the different classes of rock.	(b) Time required (expressed in eight-hour shifts) for a miner to extract one cubic metre of material from the full area of a tunnel.	(c) Time required (expressed in eight-hour shifts) for a miner to extract one cubic metre of material in open-cut work.	(d) Geometrical Series, having a common ratio 1·904.	
					From column (a).	From column (b).
Soft ground.....	I.	6·51	0·154	0·08	6·51	0·153
Ground extracted with the pick.	II.	4·08	0·245	0·14	3·34	0·29
Ground separated with the gad.	III.	2·49	0·401	0·19	1·80	0·55
Rocks which are quarried......	IV.	0·87	1·149	0·47	0·94	1·05
Rocks quarried and blasted.....	V.	0·49	2·041	0·65	0·50	2·01
Rocks to be blasted............	VI.	0·26	3·903	1·04	0·26	3·846

The numbers in column (b), multiplied by the day's wages (eight hours) of a miner, will give *the cost of a cubic metre of excavation in tunneling*, while the numbers in column (c) are the coefficients which, multiplied by the wages of a good outside laborer, will furnish the cost of excavation of one cubic metre in open working. Of course, the figures for inside working are greatly in excess.

The reader's attention is directed to the remarkable fact, shown by the table, that the number of cubic metres which a miner is capable of extracting during eight hours in the six different classes of rock decreases nearly in a geometrical ratio from Classes I. to VI., while the time increases; and column (d) shows that this rate of increase and decrease is in a geometrical progression with a common ratio 1·904. It should, moreover, be noted that the numbers in column (d) are within the limits of corresponding values obtained from actual tunneling (in Europe). We have therefore the rule that the extraction of the different materials noted in the six classes specified decreases in quantity in a geometrical ratio, while the cost of extraction increases in the same ratio.

The following formulæ are given by Schoen for determining the dimensions of blast-holes and their charges with powder, referred to given areas in a rock of average character:

Let f denote the area in square metres;
l " the depth of bore in centimetres;
t " the length of the line of shortest resistance;
V " the volume of the blasted material, the face being supposed to be nearly plane and open;
d " the clear width of the hole in centimetres;
L " the charge of powder of a hole in grammes;
Z " the length of the fuse in centimetres;

we will have:

(1) l cmtrs. $= 20\sqrt{f}$ (more accurately, $= 20\cdot18\sqrt{f}$).
(2) t cmtrs. $= 14\sqrt{f}$ (more accurately, $= 14\cdot3\sqrt{f}$).
(3) V cub. cmtrs. $= 2920 f\sqrt{f}$, or
V cub. mtrs. $= 0\cdot00292 f\sqrt{f}$.
(4) d cmtrs. $= 2\cdot34 + 0\cdot4\sqrt{f}$.
(5) L grammes $= \sqrt{f}\,(28\cdot6 + 9\cdot8\sqrt{f} + 0\cdot8 f)$.
(6) Z cmtrs. $= (20\sqrt{f}) \times 2$.
(7) $V = 1\cdot05\, t^3$.
(8) $V = 0\cdot37\, l^3$.
(9) d cmtrs. $= 2\cdot34 + 0\cdot02\, l$.
(10) L grammes $= l\,(1\cdot43 + 0\cdot024\, l + 0\cdot0001\, l^2)$.

These tables and formulæ from Schoen may perhaps be of value to some readers of this work. They have never, so far as the author knows, been verified, or even discussed, in America, and their discussion alone may perhaps be a help in modifying some of our rule-of-thumb principles in blasting work.

In the use of the lower explosives—haloxyline, Reveley's powder, etc., which approximate in strength to gunpowder—the circumstances are so similar that it is hardly necessary to enter into them. As to gun-cotton, it would not seem at the present day to be likely to supersede either black powder or nitro-glycerine, in their respective provinces, being midway between the two in strength, and the lower dynamites approximate so closely to it, while in the general judgment they are so much safer to use, that they are likely to occupy the place it might fill in blasting.

Headings in Solid Rock, driven by Hand-Labor with Black Powder.

Prior to the introduction of machine-drilling and the higher explosives, of course all tunnel-work was done with black powder, and its use in tunneling is as yet by no means a thing of the past. As a general rule, in rock-tunnels driven in the United States, the heading is taken out at the top to the full width of tunnel cross-section, and about 7 feet high at the centre. Sometimes, however, as recently in the case of the Greenfield Tunnel No. 2 in Wisconsin, a small centre-heading is driven, to be subsequently enlarged at the sides. Driving headings by hand with black powder simply involves the ordinary operations of blasting before described, and it is not necessary here to enter further in detail than to give the average rates of progress that have been attained in various tunnels. These will be found arranged in the following tables:

TABLE 16.

RAILROAD.	NAME.	Date.	Top (T) or Bottom (B) Heading and Dimensions.	PROGRESS. M = per month. W = per week. D = per day. Single (s) or Double (d) Track. HEADING. Feet.	HEADING. Metres.	BOTTOM. Feet.	BOTTOM. Metres.	MATERIAL.	REMARKS. (In this table the rate of progress for both heading and bottom is reduced to average rate for one heading and one bottom.)
				M	M	M	M		
Albany and Susqueh'na	Webster	1865	T. 8′ × 8′	50 to 60	15·3 to 18·3	....	.... s.	Slate.	
Albany and West Stockbridge.	One Tunnel	1841	T.	53	16·2	59·9	18·2 d.	Limestone and Slate.	Driven from both ends.
Allegheny Valley.	Summit	1871	T. 10′ high (3·05)	West 79·6 East 89·1	West 24·3 East 27·1		.... d.	Fire-clay Rock.	
Baltimore and Ohio.	Greenfield Bridge	1848	T.	33	10·1	33	10·1 "	Mica Slate.	Worked chiefly from one end.
" "	Lower Point of Rocks	1867	"	33	10·1	33	10·1 "	" "	
" "	Upper Point of Rocks	1867	"	50	15·2	50	15·2 "	" "	
" "	Harper's Ferry	1839	"	27	8·2	27	8·2 "	Hornblende Slate.	
" "	Doe Gully	1839	"	100	30·5	100	30·5 "	Hard Clay Slate.	
" "	Paw Paw	1840	"	41	12·6	41	12·6 "	Soft Clay Slate.	
" "	Everett's	1849	"	43	13·2	43	13·2 "	Clay, Slate, and Sandstone.	
" "	McGuire's	1851	"	38·4	11·7	50	15·2 "	Clay Slate.	Worked from both ends.
" "	Rodemer's	1850	"	42·1	12·9	38	11·7 "	" "	Worked from W. end.
" "	Kingwood	1849	"	75	22·9	70	21·3 "	Clay, Slate, and Sandstone.	Worked from ends and shafts.
" "	Murray	1850	B. 6′ (1·8)	84	25·6	84	25·6 "	Sandstone and Coal Vein.	
" "	Carr's	1853	B. and T.	132⅓	40·2	....	.... s.	S'ndst'e and Slate.	Worked from ends and shafts.
" "	Brandy Gap	1853	T.	80	24·4	59	18·0 "	" "	Worked from one end.
" "	Trough	1854	"	33·4	10·2	33·4	10·1 "	" "	" " W. "
" "	Buckeye	1853	"	42·6	13·0	42·6	13·0 "	" "	" " both ends.
" "	Shannon	1854	"	34½	10·5	165⅛	50·5 "	" "	" " " "
" "	Doe Run	1853	"	65	19·8	87	26·5 "	" "	Worked from ends and shaft.
" "	Calhanns	1855	"	191	58·2	....	.... "	" "	Worked from W. end.
" "	Cunningham's	1855	"	113	34·5	71	21·7 "	" "	" " one "
" "	Butcher	1854	"	104	31·7	....	.... "	Soft Red Shale.	" " both ends.
" "	Teneriffe	1855	"	100	30·5	75	22·9 "	S'ndst'e and Slate.	" " one end.
" "	Section 74	1853	"	94	28·7	135	41·2 "	" "	" " both ends.
" "	Glover's Gap	1852	......	60	18·3	60	18·3 "	" "	
" "	Eaton's Upper	1852	......	27½	8·3	55	16·8 d.	" "	" " " "
" "	Eaton's Lower	1852	......	55	16·8	46	14·1 "	" "	" " " "
" "	Martin's	1851	......	74	22·6	30	9·1 s.	Soft Slate.	" " E. end.
" "	Broad Tree	1851	......	69	21·0	69	21·0 "	Clay Slate.	Worked from ends and shafts.
" "	Welling	1851	......	104	31·7	178½	54·5 "	Slate and S'ndst'e.	Worked from E. end.
" "	Shepherd	1851	......	38·2	11·6	38	11·6 "	" "	" " both ends.
Baltimore and Potomac.	Baltimore	1871	......	150	45·8	45	13·8 "	Rock, Clay, Earth.	
Blue Ridge R. R.	Stump House	1855	T. Rad. = 6′ area = 56¼°	25–30	7·6–9·1	25–30	7·6–9·1 "	Mica-schist and Gneiss.	
				D	D	D	D		
Central Pacific.	Cisco	....	......	0·79	0·24	0·89	0·27 s.	Hard Trap.	
" "	Red Spur	....	......	0·72	0·22	0·91	0·28 "	" "	
" "	Crocker's Spur	....	......	0·60	0·18	0·89	0·27 "	Granite.	
" "	Summit	....	......	1·18	0·36	1·42	0·43 "	"	
" "	"	....	......	1·82	0·55	4·38	1·34 "	"	This advance made with nitro-glycerine.
" "	"	....	......	0·88	0·27	1·57	0·46 "	"	
" "	Black Point	....	......	0·94	0·29	1·44	0·44 "	"	
" "	Donner's Peak	....	......	1·26	0·39	1·42	0·44 "	"	
" "	Cement Ridge	....	......	2·51	0·76	3·56	1·09 "	Conglomerate.	
" "	Tunnel Spur	....	......	1·62	0·50	1·17	0·35 "	Granite decomposed.	
" "	" "	....	......	1·28	0·39	1·97	0·60 "	Granite decomposed.	
" "	Lake Ridge	...	......	2·24	0·68	2·24	0·68 "	Conglomerate.	
				M	M	M	M		
Delaware, Lackawanna and Western	Bergen	1874	T. 7′ to 8′ high.	22·2	6·7	22·6	6·8 d.	Dolerite.	
Louisv'le and Cincinnati	Seven Tunnels	1867	T. Rad. = 7′ area = 77°.	80′ to 100′	24·4–30·5	80′–100′	24·4 s. 30·5 "	Limestone and Fire-clay.	
Louisville, Nashville, and Great Southern	Madry Hill	1859	T.	44	13·5	56	17·1 "	Limestone.	Three hammers in each shift.
New York and Canada.	Fort Ticonderoga	1874	T. 6′ × 10′	40	12·3	30–40	9·1–12·3 "	"	Nitro-glycerine employed.
" "	Port Henry	1874	T. 6′ × 10′	40	12·3	30–40	9·1–12·3 "	"	Nitro-glycerine employed.
" "	Willsborough	1874	T. 6′ × 10′	40	12·3	30–40	9·1–12·3 "	"	Nitro-glycerine employed.

TABLE 16. (*Continued*).

RAILROAD.	NAME.	Date.	Top (T) or Bottom (B) Heading and Dimensions.	PROGRESS. M = per month. W = per week. D = per day. Single (s) or Double (d) Track.				MATERIAL.	REMARKS. (In this table the rate of progress for both heading and bottom is reduced to average rate for one heading and one bottom, except in the Southern Pacific tunnels.)
				HEADING.		BOTTOM.			
				Feet.	Metres.	Feet.	Metres.		
				D	D				
New York and Harlem.	Fourth Ave., N.Y. City.	1872	T. 7′ high	5	1·5	....	.... s.	....	"Progress about 5′ per day in each tunnel."
						M	M		
Phila. and Reading.	Black Rock	1835	......	0·78 12 hrs.	0·24 12 hrs.	40½	12·4 d.	Graywacke.	From ends. Enlargements taken from J. Laurie's Hoosac Report.
" "	" "	1835	......	0·58	0·18	33	10·1 "	"	Heading from shafts (J. Laurie).
" "	Pulpit Rock............	1839	......	....	...	47	14·4 "	Sandstone.	Progress from ends (J. Laurie).
" "	" "	1839	......	...	...	34	10·4 "	"	Progress from shafts (J. Laurie).
				M	M				
Southern Pacific.	No. 1..................	1875	T. Rad. 9′ 6″ area 141·8	114	34·8	127	38·7 s.	Decomposed Granite.	Worked from both ends.
" "	" 2..................	1875	Rad. 10′ area 157	54	16·5	49	15·0 "	" "	Worked from lower end.
" "	" 3..................	1875	"	128	39·0	128	39·0 "	" "	Worked from both ends.
" "	" 4..................	1875	"	86	26·2	82	25·0 "	" "	Worked from both ends.
" "	" 5..................	1875	"	131	39·9	144	44·0 "	" "	Worked from both ends.
" "	" 6..................	1875	"	54	16·5	55	16·8 "	" "	Worked from both ends.
" "	" 7..................	1875	Rad. 8′ 6″ area =113·5	66	20·1	82	25·0 "	Hard decomposed Granite.	Worked from both ends.
" "	" 8..................	1875	Rad. 8′ area = 100·5	91	27·7	115	35·1 "	Hard decomposed Granite.	Worked from both ends.
" "	" 9..................	1875	Rad. 9′ 6″ ar. 141·8	116	35·4	116	35·4 "	Hard decomposed Granite.	Worked from both ends.
" "	" 10..................	1876	R. 8′ 6″ ar. 113·5	105	32·1	116	35·4 "	Hard decomposed Granite.	Worked from both ends.
" "	" 11..................	1876	R. 9′ 6″ ar. 141·8	53	16·2	53	16·2 "	Granite.	Worked from one end.
" "	" 12..................	1876	R. 10′ area = 157	118	36·0	108	32·9 "	Decomposed Granite.	Worked from both ends.
" "	" 13..................	1876	"	110	33·5	108	32·9 "	" "	Worked from both ends.
" "	" 14..................	1876	"	100	30·5	99	30·2 "	" "	Worked from both ends.
" "	" 15..................	1876	R. 9′ 6″ ar 146·8	66	20·1	69	21·0 "	" "	Worked from both ends.
" "	" 16..................	1876	R. 10′ area = 157	84	25·6	86	26·2 "	" "	Worked from both ends.
" "	" 17..................	1876	"	62	18·9	67	20·4 "	" "	Worked from both ends.
" "	" 18..................	1876	"	90	27·4	174	53·1 "	" "	Worked from both ends.
" "	" 19..................	1876	R. 9′ 6″ ar 147·8	152	46·4	213	65·0 "	" "	Worked from both ends.
" "	San Fernando, No. 20..	1875	R. 9′ 6″ ar. 141·8	446	135·9	435	132·5 "	Sandstone of varying hardness.	Worked from ends and from three inclines.
				D	D	D	D		
Union Pacific.	No. 1..................	1868	......	4	1·2	6	1·83 "	Soft Sandstone.	
" "	" 2..................	1868	......	4	1·2	9	2·74 "	Clay Rock.	
" "	" 3..................	1868	......	1·08 2·70 4·62	0·31 0·82 1·41	0·57 3·17 4·62	0·17 " 0·96 " 1·41 "	Black Limest'ne with Quartzite.	Mormons, with powder. Gentiles, with powder. Gentiles, with nitro-glycerine.
" "	" 4..................	1868	......	1·38	0·41	0·92 8·18	0·28 " 4·50 "	Quartzite.	Powder. Mormons, with nitro-glycerine.

AVERAGE PROGRESS IN THE UNITED STATES OF TUNNELS DRIVEN BY HAND-LABOR WITH BLACK POWDER.

Recapitulation of 21 tunnels through hard, solid rock, such as granite, porphyry, trap, etc.; also solid, tough rock, like limestone:

Monthly Progress { Heading ....36·02 feet, 10·98 metres.
Bottom ....49·00 " 14·94 "

Daily Progress { Heading .... 1·44 " 0·44 "
Bottom .... 1·96 " 0·60 "

Recapitulation of 58 tunnels through easier rock—slate, shale, mica-schist, sandstone, partially decomposed granite, etc.:

Monthly Progress { Heading ....63·76 feet, 19·43 metres.
Bottom ....65·47 " 19·96 "

Daily Progress { Heading .... 2·55 " 0·78 "
Bottom .... 2·62 " 0·80 "

TABLE 17.

AVERAGE MONTHLY PROGRESS OF DOUBLE-TRACK TUNNELS IN EUROPE DRIVEN BY HAND-LABOR.*

CHARACTER OF GROUND.	HOISTING THROUGH A SHAFT.				HAULING THROUGH HEADING.		
	Shaft of 10 to 15 sq. m †	Heading of 7 to 9 sq. m.	ENLARGEMENT.		Heading of 7 to 9 sq. m.	ENLARGEMENT.	
			If there is but one starting point.	If there are more starting points.		If there is but one starting point.	If there are more starting points.
	Metre.	Metre.	Metre.	Metre.	Metre.	Metre.	Metre.
1. In very solid, firm rock, with partial timbering...........	6 to 10	10 to 12	5 to 6	4 to 5	12 to 15	6 to 8	5 to 6
2. In solid rock, with light timbering.....................	15 to 20	20 to 25	8 to 12	6 to 10	20 to 25	10 to 15	8 to 12
3. In soft ground, with stout timbering..................	30 to 35	35 to 40	12 to 18	10 to 12	40 to 50	15 to 20	12 to 15
4. In very heavy, soft ground, with very stout timbering...	20 to 25	30 to 35	8 to 12	6 to 10	35 to 40	10 to 15	8 to 12

This table is based on statements of European engineers. The cross-section area of tunnel is assumed to be 50 to 56 square metres. The figures for progress, if materials are hoisted through a shaft, are for a maximum depth of 100 metres; they would be perceptibly diminished with increased depth of shaft.

Rziha has compiled the following table‡ from various records of European work to show that the rate of advance per month attained in construction is apt to be greater in long than in short tunnels. This follows from the fact that generally a certain time, approximating as nearly as may be to the completion of the other portions of the railroad, is fixed by contract for the completion of the tunnel, and means must be found to keep within it. Moreover, with very long tunnels, there is generally a premium offered for rapid work, and a forfeit stipulated if the work is not completed within a certain date. The table is unique and of great interest.

Owing to the fact that, in America, our tunnels are generally under 1500 metres in length, we cannot as yet have so wide a basis of comparison. Still, we know, from general experience, that the rule holds good here also.

* From A. Lorenz's "Förderung bei Tunnelbauten," Zurich, 1876. (Translated by Mr. F. Rinecker, C.E., of Würzburg, Germany, for this work.)

† 1 metre = 3·281 feet: 1 sq. metre = 10·7642 sq. feet = 1·196 sq. yards.

‡ "Lehrbuch der Gesammten Tunnelbaukunst," vol. ii, pp. 173, 174, 175.

TABLE 18.

Number.	NAME OF TUNNEL.	Highway, H.; Canal, C.; Railroad, R.R.	When commenced.	Length in Metres.	Time in Months.	Metre of Tunnel finished per Month.	AUTHORITY.
			A. Tunnels not 100 Metres Long.				
1	Läufelfinger Fluh......R.R.	Switzerland Central R.R.	1854	58	8	6·9	Pressel u. Kauffm'n, Bau d. Hauenst'n
2	Aarburg .... “	“ “ “	1855	69	9	7·7	“ “ “ “
3	Hecheln............... “	Vereinigte Schweizer R.R.	1858	83	7	11·8	“ “ “ “
			Average..........	....		8·8 m. = 29 feet.	
			B. Tunnels from 100 to 200 Metres Long.				
4	Obere Glattwand......R.R.	Vereinigte Schweizer R.R.	1858	107	10	10·7	Pressel und Kauffmann.
5	Rossplatte............ “	“ “ “	1857	108	14	7·7	“ “
6	Bühl.................. “	“ “ “	1857	113	9	12·5	“ “
7	Stutz.................. “	“ “ “	1858	120	13	9·2	“ “
8	Montretout .... “	Paris-Versailles R.R.	1838	168	13	13·0	Toni-Fontenay, Tunnel de St. Cloud.
9	Chalifert.............. “	Paris-Strassburg R.R.	....	168	18	9·4	Zeitschrift für Bauwesen, 1862.
10	Bommelstein. .... “	Vereinigte Schweizer R.R.	1856	178	13	13·7	Pressel und Kauffmann.
11	Hardelôt .... “	French Northern R.R.	....	184	18	10·2	Zeitschrift für Bauwesen, 1862.
12	Untere Glattwand... . “	Vereinigte Schweizerbahn.	1858	198	9	22·0	Pressel und Kauffmann.
13	Weisswand.... .... “	“ “	1858	200	10	20·0	“ “
			Average			12·8 m. = 42 feet.	
			C. Tunnels from 200 to 400 Metres Long.				
14	Ippens.... ............R.R.	Brunswick R.R. (Ger.).	1862	210	9	23·7	
15	Revin.. ....C.	Maas Canal.	1838	213	29	7·4	Stuttgarter Eisenbahnzeitung, 1849.
16	Hoffmühl..............R.R.	Paris-Strassburg R.R.	....	247	48	5·2	Zeitschrift für Bauwesen, 1862.
17	Standenhorn........... “	Vereinigte Schweizer R.R.	1858	248	8	31·0	Pressel und Kauffmann.
18	Ofeneck.... .... “	“ “ “	1858	250	9	27·7	“ “
19	Venables.............. “	Rouen R.R.	1841	265	20	13·2	Zeitschrift d. hannoverschen V. d. Ing. IV.
20	Papur.................. “	Swiss Central R.R.	1855	270	14	19·3	Pressel und Kauffmann.
21	Chalifert..................C.	Marne Canal.	1842	290	48	6.0	Stuttgarter Eisenbahnzeitung, 1849.
22	Rohrlach.............R.R.	Silesian Mountain R.R.	1865	294	14	21·0	Zeitschrift für Bauwesen, 1868.
23	Haut Barr............. “	Paris-Strassburg R.R.	. . .	304	47	6·0	“ “ “ 1862.
24	Schönhut.............. “	Silesian Mountain R.R.	1865	307	18	17·1	“ “ “ 1868.
25	Wiebelskirch.......... “	Rhine-Nahe R.R.	1857	312	26	12·0	“ “ “ 1862.
26	Luzerne.......... .... “	Swiss Central R.R.	1857	319	18	17·7	Pressel und Kauffmann.
27	Batignolles I.......... “	French Western R.R.	....	333	18	18·5	Zeitschrift für Bauwesen, 1862.
28	Rosenstein.... .... “	Würtemberg R.R.	1844	368	18	20·1	Stuttgarter Eisenbahnzeitung, 1849.
29	Hommerich .... “	Rhine-Nahe R.R.	1857	388	22	17·6	Zeitschrift für Bauwesen, 1862.
30	Liverdun ....C.	Marne-Rhine Canal.	1839	380	57	6·6	Stuttgarter Eisenbahnzeitung, 1849.
31	Bas Rhin I........ ....R.R.	Paris-Strassburg R.R.	....	400	36	11·1	Zeitschrift für Bauwesen, 1862.
			Average........................			15·7 m. = 51½ feet.	
			D. Tunnels from 400 to 600 Metres Long.				
32	Arschwiller II...........C.	Marne-Rhine Canal.	1840	410	57	6·1	Stuttgarter Eisenbahnzeitung, 1849.
33	Lützelburg............R.R.	Paris-Strassburg R.R.	....	439	52	8·4	Zeitschrift für Bauwesen, 1862.
34	Chezy................. “	“ “ “	....	453	32	14·1	“ “ “
35	Aarau................. “	Swiss Central R.R.	1856	465	18	25·8	Pressel und Kauffmann.
36	Tourville............... “	Rouen R.R.	1841	465	18	25·8	Zeitsch. des hannov. Ver. d. Ing. IV.
37	Bildstock............. “	Saarbrück R.R.	....	480	..	18·8	Zeitschr. für B. H. u. S. W., 1857.
38	Bas Rhin II........... “	Paris-Strassburg R.R.	....	498	48	10·3	Zeitschrift für Bauwesen, 1862.
39	St. Cloud.............. “	French Western R.R.	1837	504	15	33·6	Toni-Fontenay, Tunnel de St. Cloud.
40	Rive de Gier.............C.	Canal Givors.	1770	506	36	14·0	Minard, Cours de construction.
41	Triebitz...............R.R.	Prague-Olmütz R.R.	1842	510	29	17·6	
42	Burgdorf.............. “	Swiss Central R.R.	1855	510	24	21·2	Pressel und Kauffmann.
43	Oberau............... “	Leipzig-Dresden R.R.	1837	512	32	16·0	Romberg's Zeitshrift, 1843.
44	Han ....C.	Maas Canal.	1838	554	34	16·3	Stuttgarter Eisenbahnzeitung, 1849.
45	Pagny...............R.R.	Paris-Strassburg R.R.	....	572	33	17·3	Zeitschrift für Bauwesen, 1862.
			Average........................			17·5 m. = 57½ feet.	
			E. Tunnels from 600 to 1000 Metres Long.				
46	D'Armentier...........R.R.	Paris-Strassburg R.R.	....	656	34	18·7	Zeitschrift für Bauwesen, 1862.
47	Colancelle..................		....	750	15	50·0	Pressel und Kauffmann.
48	Durch die Prag........R.R.	Würtemberg R.R.	....	831	21	39·5	Stuttgarter Eisenbahnzeitung, 1849.
49	Feng......................C.	Marne-Rhine R.R.	1839	868	46	18·8	“ “ “ “
50	*Saltwood.............R.R.	London-Dover R.R.	1842	873	12	72·8	Simms' Practical Tunneling.
51	†Naens................. “	Brunswick R.R.	1861	879	37	23·7	Ržiha.
52	Kirchheim am Neckar. “	Würtemberg R.R.	....	885	21	27·8	Stuttgarter Eisenbahnzeitung, 1849.
53	Cumptich	Louvain R.R.	1835	925	24	38·5	Minard, Cours de construction.
54	Nanteuil	Paris-Strassburg R.R.	....	944	41	23·0	Zeitschrift für Bauwesen, 1862.
			Average...................... .			34·7 m. = 114 feet.	

* This tunnel was driven with two portals and twelve shafts.

† This tunnel was driven with one portal and one shaft.

Number.	Name of Tunnel.	Highway, H.; Canal, C.; Railroad, R.R.	When commenced.	Length in Metres.	Time in Months.	Metre of Tunnel finished per Month.	Authority.
		F. Tunnels from* 1000 *to* 2000 *Metres Long.					
55	Charonne..............R.R.	Paris Connection R.R.	....	1020	22	46·4	Zeitschrift für Bauwesen, 1862.
56	Fong.................. "	Paris-Strassburg R.R.	....	1121	37	30·3	" " " "
57	Belleville............. "	Paris Connection R.R.	....	1125	22	51·1	" " " "
58	Blechingly .... "	London-Dover R.R.	1840	1211	24	57·6	Simms.
59	Torey...................C.	Centre Canal.	1787	1267	24	50·3	Minard.
60	Charleroy .... "	Charleroy Canal.	1828	1288	48	26·8	"
61	Lioran.................. ..H.	National Highway, No. 126.	1839	1386	80	17·3	Stuttgarter Eisenbahnzeitung, 1849.
62	Semmering Main T........	Vienna-Trieste R.R.	1849	1430	36	39·7	
63	Terre Noire...........R.R.	Lyon-St. Etienne R.R.	1826	1500	36	41·7	Minard.
64	Roule	Rouen R. R.	1841	1720	20	85·4	Stuttgarter Eisenbahnzeitung, 1849.
				Average...		44·7 m. = 147 feet.	
		G. Tunnels from* 2000 *to* 3000 *Metres Long.					
65	Liverpool ............R.R.	Liverpool-Manchester.	...	2025	24	84·3	
66	Kilsby........... ... "	London-Birmingham.	1834	2204	48	45·9	Minard.
67	Arschwiller I ....C.	Marne-Rhine Canal.	1839	2250	72	31·2	Stuttgarter Eisenbahnzeitung, 1849.
68	Hauenstein.............R.R.	Swiss Central R.R.	1853	2496	60	41·6	Pressel und Kauffmann.
69	Harecastle I..............C.	Grand Trunk Canal.	1770	2600	84	30·9	Minard.
70	Harecastle II............ "	" " "	1825	2630	50	52·6	"
71	Rollebois..............R.R.	Rouen R.R.	1841	2642	24	110·0	Stuttgarter Eisenbahnzeitung, 1849.
72	Arschwiller............ "	Paris-Strassburg R.R.	....	2678	93	29·8	Zeitschrift für Bauwesen, 1862.
73	Blisworth................C.	Grand Junction Canal.	1798	2820	84	33·5	Minard.
74	Box............................	....	....	2850	48	59·3	Pressel und Kauffmann.
				Average		51·9 m. = 170 feet.	
		H. Tunnels from* 3000 *to* 4000 *Metres Long.					
75	Marley.................R.R.	Leeds-Manchester R.R.	....	3073	36	85·3	
76	Poully....................C.	Bourgogne Canal.	1824	3330	96	34·6	Minard.
77	Rilly ....R.R.	Paris-Strassburg R.R.	....	3450	40	86·2	Zeitschrift für Bauwesen, 1862.
78	Sousey..................C.	Bourgogne Canal.	1826	3521	84	42·0	Minard.
79	Thames-Medway .... "	Thames-Medway Canal.	1822	3620	36	100·6	"
80	Sapperton............... "	" " "	1783	3830	72	53·2	"
				Average		66·9 m. = 219½ feet.	
		I. Tunnels from* 4000 *to* 6000 *Metres Long.					
81	Blaisy..................R.R.	Paris-Lyon R.R.	1846	4025	39	105·0	Förster's Bauzeitung.
82	La Nerthe............. "	Avignon-Marseilles.	....	4628	48	96·4	Stuttgarter Eisenbahnzeitung, 1849.
83	Manvage.................C.	Marne-Rhine Canal.	1840	4800	82	58·5	" " "
84	Riqueval .... "	St. Quentin Canal.	1803	5675	82	68·7	Minard.
				Average.........................		82·1 m. = 259 feet.	
		K. Tunnel more than* 6000 *Metres Long.					
85	Noirieu.......... ....C.	St. Quentin Canal.	1822	12000	84	142·8	Minard.

Tunneling with the Higher Explosives.

As to the use of the higher explosives in tunnel-work, there cannot as yet be given any rigid limits with reference to cost or rate of progress. In Chapter VI. will be found full accounts of the construction of the six prominent modern tunnels in the United States and Europe. In them all, except the first (Nesquehoning), nitro-glycerine in some form was used, either pure or in combination as a dynamite. These tunnels must be taken as the best types that can as yet be offered of such work.*

Blasting with high explosives offers the pointed advantage that, owing to their great strength, the holes can be set either perpendicularly to the face—*i. e.*, in the line of least resistance—or at a very acute angle, while we have seen that, in general, black powder must be

* And see notes on the performance of rock-drills and explosives at Hell Gate, pp. 252 and 390 of this work.

charged at an angle of 45° or less in firm, unfissured rock. In Europe, this property has led to the holes in a narrow heading being set normal to the face, with no bearing; and in America, though holes normal to the face are not the rule, deeper holes are drilled at a lesser angle than could possibly be taken with black powder. Now, were there space in this work for them, there might be given an infinite number of results of various trials that have been made as to the relative amounts of rock blasted in different materials with gunpowder and with the higher explosives; but, after collecting a large quantity of these results, the values obtained are so conflicting, owing to the wide diversity of circumstances occurring, that the author of this work has concluded to here confine the discussion to the results obtained in tunnel-heading driving.

In this connection, the reader is also referred to General John Newton's Annual Reports to the Chief of Engineers U. S. A., for 1873, 1874, 1875, 1876, on "The Removal of Obstructions at Hell Gate," etc.; and to a paper by Mr. Julius H. Striedinger, on "The Simultaneous Ignition of Thousands of Mines," read before the American Society of Civil Engineers, April 4th, 1877. See Transactions of the Society, Vol. VI., No. 162. Also, see "The Scientific American," Vol. XXXV., N. S., pp. 214, etc. (September 30th, 1876), for a full illustrated article on "The Removal of the Hell Gate Rocks;" and "The New York Herald," September 25th, 1876, and see performance of rock-drills and explosives at Hell Gate, p. 252 of this work. As to other submarine blasting, see Report of Major R. S. Williamson and Captain W. H. Heuer on "Removal of Blossom Rock, San Francisco Harbor." There are also a number of reports from other engineers in the U. S. service on submarine blasting; among them may especially be noted those of Mr. E. P. North and L. W. Schermerhorn in 1876, and General Henry L. Abbot's exhaustive discussion on the comparative strength of explosive compounds when fired under water, and his discussion of electrical fuses, No. 23 of Professional Papers of the Corps of Engineers, U. S. A., 1881. See also paper on "The Method of Blasting Rock for the Lyttleton Harbor Works at Canterbury, New Zealand," by George Thornton, "Van Nostrand's Magazine, vol. xxi., p. 77.

See also for "Rules for Blasting," etc., the following references: Gillespie's "Roads and Railroads," p. 61; "Civil Engineers' and Architects' Journal," vol. ii., p. 256, July, 1839; "The Mechanics' Magazine," vol. xxxiii., p. 597, 1840; "London Mechanics' Magazine," vol. xlvi., p. 407, April, 1847, and p. 455, May, 1847 (this last reference is to some experiments on the comparative strength of gun-cotton and gunpowder).

See also the "Manufacturer and Builder," September, 1882, p. 206, article on "Blasting by Quick-lime Cartridges," and the "Engineering and Mining Journal," New York, December 16, 1882, vol. 34, p. 319, for notes from a paper by Arthur Sopwith on trials of blasting with the "Lime Process" in England.

Record of Heavy Blasts.

The following references contain records of heavy blasts that have been made: "Blasting at Holyhead," see "Civil Engineers' and Architects' Journal," vol. xxiv., February, 1861; also vol. xix., p. 101; at "Furness Granite Quarry," "Civil Engineers' and Architects' Journal," vol. xv., p. 400; at "Abbot's Cliff" and "Round-Down Cliff," Dover, "Civil Engineers' and Architects' Journal," vol. vi., pp. 68, 165, and 398, 1843; at "Round-Down Cliff," Dover, "Mechanics' Magazine," vol. xxxviii., p. 62, London, July 24th, 1843; in Algiers, "The Builder," May 18th, 1850; at Isle of Wight, "Mechanics' Magazine," London, vol. lviii., p. 90, 1853; at Seaford, "The Builder," vol. viii., p. 453, September 21st, 1850; at "Downhill," "Civil Engineers' and Architects' Journal," vol. ix., p. 253, 1846; at "Acre Flat," Dover, "Civil Engineers' and Architects' Journal," vol. vi., p. 187; on the Clyde, "Iron," vol. vi., p. 619, 1875; at the Furnace Granite Quarries, "Iron," August 16, 1879, p. 194; the Great Blast at Glendon, "Transactions American Institute of Mining Engineers," vol. vii., p. 266.

CHAPTER V.

AIR-COMPRESSORS AND MACHINE ROCK-DRILLS.*

PART I.

AIR-COMPRESSORS.

IN treating the subject of air-compressors, it has been deemed well to divide this chapter into the following sub-heads:

Uses and Applications of Compressed Air; Early Compressors; Discussion of the various Systems employed in Designing, Constructing, and Operating Compressors; Description and Illustration of the later forms of Compressors upon the Market; Discussion of Indicator Diagrams from various Compressors, showing the Faults of the Machines from which they were taken; Instruction for Setting Up and Using Compressors; Efficiency of Air Compressors; Loss in Transmission; Capacities of Compressors; Lists of American and British Patents up to July 1st, 1881; Lists of Books, Papers, and Newspaper Articles upon Air-Compressors and the Employment of Compressed Air.

USES AND APPLICATIONS.

Air under pressure is employed for the transmission of power, as the principal or auxiliary of various industries, in mines, in quarries, well-driving, building bridge piers, in tunneling, in the production of cold, in sugar-making and refining, and various chemical works, the manufacture of iron and steel, for ventilating mines or buildings, for transmitting letters or packages in pipes placed underground or otherwise, in driving clocks, street cars, yachts, torpedoes, etc., etc. It makes no dirt, and liberates no offensive gases. For the transmission of power it has the advantages over steam that it can be carried for any distance without losing any power by condensation or cooling; it is drier and cooler than steam; and in mines and tunnels, instead of rotting timbers and heating the galleries, it gives good forced ventilation by good, pure, cool air. It can be applied in any direction and around corners; and, by the use of flexible pipes, may be moved as the work changes; it may be used economically and applied with little loss from friction. As an instance of this last, it is said that in the Hoosac tunnel air was carried 7150 feet in 8-in. iron pipes, its pressure falling from 67 pounds only 2 pounds.

EARLY COMPRESSORS.

Ctesibus, 3d century B.C., discovered that air was compressible, and his pupil, Hero of Alexandria, wrote a book to prove it, and made the first recorded experiments on compressing

* The author is indebted to Professor De Volsom Wood, and to Dr. Robert Grimshaw, for much assistance in the study and elaboration of matter in this chapter. Also to many of the leading manufacturers of Rock-Drills and Compressors throughout the United States and Europe, who have placed at the author's service many drawings and much information, otherwise unattainable.

air; but from that time till Papin's date (17th century), when the latter proposed its use for running engines, but little was heard of it.

In 1650, Otto Von Guericke invented the air-pump.* In 1726, Rowe took out a patent in England for raising water by generated, expanded, or compressed air.† In 1753, Holl, at Schemnitz,‡ used an "air-engine," which, in the Amalia shaft, raised from 9120 to 10,944 buckets of water daily to the level of the Dreifaltigheit adit, a height of some 16 Klafters (114 feet). In 1757, Isaac Wilkinson patented a method of compressing air by the use of a column of water having a series of vessels, using one after the other, so as to keep up a constant pressure. In 1810, the elder Brunel took out a patent for a machine which he describes as a vessel containing cold water, in which is fixed an Archimedian screw, by means of which the air is forced down to a suitable depth in the water. It then escapes into an inverted funnel, and thence through a pipe, by which it is conveyed to the lower part of a vessel containing hot water. In this vessel is an overshot-wheel, and the escape of the air from the conducting pipe is so directed that it ascends beneath the buckets of the wheel, where it was to produce, by its buoyancy, an effect of the same kind as would be produced by water delivered into the descending buckets of the wheel, if the wheel were placed in the open air instead of being immersed in hot water. The patent is, in fact, an attempt to obtain perpetual motion.

Jones and Plimley took out a patent in 1818 for a kind of telescopic pump, the lower tube being filled with water to serve as a packing for the upper.

In British patent No. 2299, Feb. 28, 1799, George Medhurst compresses air for motive power by means of a windmill.

George Medhurst, in British patent No. 2431, Aug. 2, 1800, has a wild idea of an engine working by air compressed by wind, or by hand, or by gunpowder.

April 29, 1828, Bompas, in a provisional British patent, No. 5644, proposed to propel locomotives by compressed air; and, in the same year, it is said that Colladon proposed to Brunel to employ it in the Thames tunnel.

June 1, 1829, Mr. William Mann, in British patent No. 5797, made a decided advance in the principles of air-compression. He states that, by the application of compressed air, power and motion can be communicated to fixed machinery, carriages, locomotives, and ships. After a general description of the application of his patent, he describes his method of pumping and compressing air, saying: "The condensing-pumps used in compressing the air I make of different capacities, according to the density of the fluid to be compressed—those used to compress the higher densities being proportionally smaller than those previously used to compress it at the first or lower densities," etc.

James Surrey, in British patent No. 7179, September 1, 1836, claims the use of compressed air for steam for the purpose of working engines hitherto worked by steam, and suggests portable vessels filled with compressed air; especially for railways, for which also he suggests having air-pipes running from station to station.

William Lance, British patent No. 8541, June 11, 1840, claims the use of compressed air for throwing harpoons.

1841—No. 9038—Von Rathen made the following claim:

(1.) "Exclusive right of fabricating and preserving compressed air to be used as a propelling power on locomotive-carriages or railroads, common roads, rivers, or canals."

(2.) (Here the claim was further made for transmitting the power from the magazine to the locomotive, etc.)

* Ganot's Physics, 2d Ed., p. 120.

† Paper on "Air-Compression," by James Steel, C. E., "The Engineer," London, vol. xli., p. 478.

‡ Stapff, "Ueber Gesteinbohrmaschinen," p. 76.

Later, in 1844, Caligny * published his idea of applying the principle of the hydraulic ram to compressing air.

Arthur Parsey, British patent No. 10,352, Aug. 17, 1844, has a regulating valve between the reservoir and the chamber from which the air is drawn.

In British patent No. 10,920, Nov. 4, 1845, J. R. Atha compresses air by a windmill.

Sir J. C. Anderson, June 29th, 1846, No. 11,273, suggests that when a locomotive carriage descends by gravity, air-pumps shall be set at work to compress air that will be used as an auxiliary to mount the ascent.

October 7th, 1847, No. 11,897, Richard and James Fell—Compressor and receiver or reservoirs for storing the air along the track of a railroad.

Again, in the English patents we find: Nov. 2d, 1847—No. 11,932—Von Rathen describes the process of cooling the air by water in the cylinder, or by surrounding the vessels with cold water. He also describes a reservoir for storing air, a refrigerator for cooling the air after its compression, and a mode of heating the air to give it greater tension after it is compressed.

In 1852, Colladon patents its application for driving machine drills in tunnels, at present one of its most important applications.

In 1854, the same patentee, however, describes a method of pumping air in which he claims the construction of end-valves, so as to cover the whole end of the cylinders to which they are applied, and repeats Mr. Mann's process of stage-pumping (patented twenty-five years before) in the following words: "The construction of air-pumps with a series of cylinders progressively diminishing in capacity."

N. Seward, in British patent No. 940, December 3d, 1852, claims compression of air by the action of the flow of the tide, or fall of water, using a series of chambers. In order to aid the compression he suggests the explosion of gunpowder gas in the chambers.

James Anderson, British patent No. 435, Feb. 19th, 1853, employs water jets to cool the compressed air, and afterwards heats it to increase its elasticity.

Moses Poole, in a communication, British patent No. 692, March 21st, 1853, absorbs the heat compressed by the water jet, and supplies the heat which is absorbed when the air is expanded, by artificial means.

1853—No. 2295—J. H. Johnson—Communication made by Sommeiller as to his hydraulic compressor.

By a patent in 1853, a Mr. Anderson claims to be the first to inject cold water into air-pumps to reduce the temperature and bulk of the air to be compressed. He says: "The air or other matter employed for obtaining motive power is principally condensed to a considerable extent, while a jet of cold water is employed to cool or reduce the temperature of the body being compressed. This treatment economizes the power employed in the compression, by annihilating the evolved heat."

In 1853, Piatti submitted several projects to the Italian ministry relative to the construction of the Mt. Cenis Tunnel, which treated especially of the employment of water-power to compress air for a motor for rock-drills in driving the tunnel, and for running trains through the tunnel both during its construction and afterward.

Previously to this, however, in 1852, Colladon filed his petition for a patent in Italy for the use of compressed air in running machine-drills in a tunnel.† To Colladon, in fact, is said to be due the essential features of the compressor systems of Mt. Cenis and St. Gothard. (See "*Die Maschinellen Arbeiten zur Durchbohrung des Gotthardtunnels*," by Prof. D. Colladon, Zurich, 1876, p. 13; also, "*Rapport Trimestriel*," etc., No. 5.) A controversy arose between

* Stapff, "Ueber Gesteinb.," p. 64.

† It is said that Colladon, as far back as 1828, proposed to Brunel to use compressed air to keep the water out of the first Thames Tunnel.

Piatti and Caligny on the one side against Sommeiller and others as to the best system of compression. A report of the discussion will be found in the "Practical Mechanics' Journal," 1865, June, p. 65, and 1866, January, p. 311. In March, 1854, Sommeiller, Grandis, and Grattoni were appointed to make a set of experiments, which were discontinued; they were resumed again in 1856 at St. Pierre d'Arena. Finally, the compressor systems of Mt. Cenis were established, and, as we have seen, the drills put to work in full during 1861.

January 15th, 1854—No. 88—Arthur Parsey (British), double-acting air-pump with hollow piston and rod, through which air is admitted above and below the piston. The valve may be as large as the cylinder. The rod passes through the valve and has a spiral spring to keep the valve seated. In this patent stage-pumping is mentioned. There is an air-reservoir for restoring air, being a vertical cylinder moving upon a fixed piston. Pumps work by locomotive engine when descending an incline, or stopping may be used to save power by compressing air.

April 1st, 1854—No. 745—Frederick S. Thomas (British) distinguished himself by proposing to propel railway carriages by collecting air by a series of fans or blowing-machines worked by the wheels.

In the British patent of John Chillcott Purnelle, No. 1641, July 26, 1854, there is proposed to employ a vacuum as a motive power.

Frederick S. Thomas, October 4th, 1854, No. 21,289 (provisional protection only)—A locomotive collecting, compressing, and expanding atmospheric air. Employing fans worked by the wheel-axles, and expanding this air by caloric. It is to be noticed that in the next patent the same ingenious gentleman wishes to obtain motive power by the well-known perpetual motion device of weighty balls approaching the periphery of the wheel upon the descending side, in the centre of the wheel on the ascending side, the power, be it noted, being provided by the greater leverage on the descending side.

Thomas Staunton, in a communication, British patent No. 2504, November 28th, 1854 (provisional protection only), employs stage-pumping, and suggests driving locomotives by compressed air.

Thomas Swinburn, June 27th, 1855, No. 1467, suggests a heavy wheel on railway driving-axles or a weighted fly-wheel attached to the compressing apparatus.

The compressed air patent of Gilardeau, British patent No. 2607, Nov. 19th, 1855 (provisional only), was practically for perpetual motion.

J. H. Johnson (British patent No. 211, January 26th, 1856, communication from J. P. L. F. Datichy) suggests having a small engine and boiler on the main framing of the locomotive, to work double-action air-pumps compressing the air into a reservoir, intending to work the pumps during the stoppages at stations.

J. A. Longridge, British patent No. 1470, June 23d, 1856, is for motive power in mines.

Augustin Grass, Jan. 2d, 1857, No. 21 (provisional protection only), obtaining motive power by a steam-engine pumping air into a reservoir connected by a coil of tubes in the boiler furnace. The air in the coil becoming heated and highly elastic, to be used in an air-engine.

James Harris, in British patent No. 25, January 2d, 1857, proposes in addition to compressing air to be used at a distance in air-engines, exhausting it.

March 13th, 1858—No. 514—John Jameson (British) patent on a series of cylinders, the upper part heated by a flue, and the lower cooled by a water cistern. The plunger of each cylinder is hollow, and stuffed with charcoal or other bad conductor, and having air-passages filled with pieces of fine wire. The lower ends of the cylinders communicate with the lower end of the next by passages having check-valves. The last cylinder communicates with the last air reservoir.

J. S. Dawes, in British patent No. 2503, June 9th, 1858, suggests portable reservoirs of compressed air to be used in driving agricultural engines.

J. T. Pitman, in a communication from W. A. Royce, British patent No. 1955, September 2d, 1858, employs the lower end of the piston-rod as a pump, to force water through the piston.

Wright and Mercer, in British patent No. 2530, November 11th, 1858 (provisional only), work a series of pumps by eccentrics, so that the pump strokes follow each other in regular order, and then use the condensed air in working the engine, power of which is communicated to the shaft by which the pumps are worked.

J. W. Hart, in British patent No. 318, February 4th, 1859 (provisional protection not allowed), is to force air and water by the turning of a slottled tube having a coil of sheet metal wrapped around it, and immersed in a chest of water.

W. H. Crispin, British patent No. 341, Feb. 7th, 1859, compressing air by pendulum vibrated by the motion of the ship.

James Tangye, in British patent No. 2325, August 12th, 1859 (provisional only), intended to compress air in reservoirs, and distribute it by pipes.

George Lough, in British patent No. 2819, December 12th, 1859 (provisional), proposes for the air-pump piston a hollow conical saddle having an india-rubber disc, with its edge covered with a leather belt, and the air, after having done its work, is sent to an air-tight fire-place.

John Jameson, British patent No. 72, January 11th, 1860, improved his patent No. 514, of 1858, by employing different reservoirs, receiving compressed air from the cylinders when heated, and giving it back to the cylinder at the end of the stroke.

D. Ruchet, J. Von Willer, and F. Seiler, in British patent No. 119, January 17th, 1860, proposed to rotate a bucket-wheel by means of compressed air, and also to compress air by the reversal of the machine.

In the British patent of Barton, Shepherd, and Evans, No. 630, March 8, 1860, air is forced into a heating furnace, to be used as a motive power. The forcing is accomplished by a number of balls which fall upon pistons, and are worked again by a screw, presumably worked by the engine.

J. Williams, in British patent No. 2779, November 13th, 1860, proposes to get motive power by sinking a shaft, at the bottom of which are to run horizontally a series of circular tunnels, the air in which is compressed by the entrance of water. The peculiar part of this patent is that the tunnels are to be emptied of water by again forcing air down!

F. H. Edwards—December 7th, 1860, No. 2999—A cylinder, the lower part furnace-heated, and the upper part water-cooled. The plunger was encircled by a belt of fine wire to absorb the heat of the ascending body of air, and to heat the descending body. The air is obtained from a reservoir of low-pressure compressed air, passing nearly cold in the higher-pressure reservoir, and after working an engine, returning to the lower-pressure reservoir.

Richard Feely—September 13th, 1861, No. 7228—Provisional protection on compressing and rarefying air to obtain a motive power, a part being applicable for cooking.

H. A. Jowett, in British patent No. 2110, July 25, 1862, proposes compressing air by water power, and carrying it long distances in pipes, having sliding-valves at regular intervals, to test their tightness, and plugs at suitable stations, which will yield motive fluid to drive fire pumps.

C. P. Stewart and John Kershaw, in British patent No. 1092, April 30, 1863, propose actuating a body of water by a horizontal piston worked by a duplex steam-engine, having several vertical vessels in which the compression is gradual. The air is to be utilized in a compound air-engine.

T. T. Coughin, in British patent No. 1741, July 13th, 1864 (provisional only), proposes stage-pumping with pumps having progressively diminishing diameters, and worked by toothed wheels, the teeth of which increase in number as the air pressure increases.

John H. Johnson—February 9th, 1864, No. 345—communication from Eugene D. Hubart, took out British patent on working pistons and cylinders by compressed air, expanded by heat before entering the valve-box, employing a portion of the power in forcing fresh air into the main receiver. The working piston-rod carries a second piston working in an air-pump, and forces air into a receiver with three valves, of which one of them opens the air-passage when the pressure decreases, and shuts it when the pressure is sufficient. The second is a safety-valve, and the third is acted on by the engine governor.

W. A. Turner and T. T. Coughin, in British patent No. 3140, December 17th, 1864, obtained provisional protection on stage-pumping, there being reservoirs between the pumps.

Handel Moore, in British patent No. 242, January 27th, 1865 (on which provisional protection was not allowed), proposed to work ships' pumps, capstans, etc., by compressed air, turning the exhaust into the stoke-hole to cause ventilation.

M. P. W. Boulton—July 22d, 1865, No. 1915—passes the valve-rod through water-cooled chambers, cools the heated air by injecting water, etc.

M. A. F. Mennons, January 27th, 1866, No. 267, acting for Nicholas de Telescheff, took out British patent on an apparatus communicating with the reservoir by means of two tubular columns with stop-cocks, and employs gaseous product of combustion to effect expansion and compression of air.

A. V. Newton, British patent No. 684, March 6th, 1866 (a communication from J. B. Atwater), claims forcing air out of a cylinder, or compressing it in a cylinder, by steam. He is to employ a revolving cylinder communicating with a rarefying cylinder drawing steam at one pound pressure from a boiler. The air heated in the rarefying chamber goes to work a hot-air engine.

In 1869, Marchant proposed to use compressed air with water for the purpose of making steam and to reheat the air, with some wild idea of increasing power.

In 1874, William Johnston, now of Philadelphia, proposed and used a series of concentric cylinders revolving upon a fixed axis and having the lower halves filled with water, the face of which served as the bottom of the pump; and in this machine, as in the later modifications thereof, stage-pumping was employed. (See later description and illustrations, p. 168.)

In the United States patent granted December 23d, 1879, to W. P. Tatham, of Philadelphia, there is a steam and an air piston, each reciprocating in a cylinder, and a double-armed rock-shaft, connected with the steam and air piston-rods, these members being combined for joint operations to compress air under a decreasing leverage of the air-piston arm, and a correspondingly increasing leverage of the steam-piston arm.

Some of the early patents quoted under the head of air-compressors may seem almost ridiculous, but it has been our object to give all, as some of them contain ideas that have been unwittingly re-patented time and again.

Robert F. Grisby, Rosario, Mexico, patented a method of lubricating the working parts of air-compressors by means of water containing carbonate of soda and borax, or other substances, to prevent oxidation of the cylinders. The proportions suggested are, water 900 volumes, oil 94, carbonate of soda 5 parts, borax 1 part.

Many efforts are being made in meeting the growing demand for air-compressing machinery in this country, to increase their efficiency by special design and special appliances. Aside from modifications and improvements in the earlier class of machinery, some new designs have been brought forward at a more recent date.

Various Systems.

Differences in usage in designing and making air-compressors are based upon about nine elements—position of cylinder, whether vertical or horizontal; the employment of water in the cylinders as a cooler and lubricant; fast or slow speed; the application of power direct

or by cranks; the use of high or low pressure air; the method of governing the supply of air; the use of cold air of uniform temperature; single cylinder or stage-pumping, and the use of positive moving valves or those opening by the pressure of the air only. The impartial critic in carefully reviewing the field, can scarcely award to any one compressor, or even to one of these elements, the merit of absolute perfection for all circumstances; for each system and each element have certain advantages and disadvantages, which may apply in one position and not in another. We give below a statement of the merits and demerits claimed for each, and the reader may judge for himself which system or which machine will best suit his particular conditions.

In every machine all moving parts should be carefully balanced, and the weight of the crank-shafts and fly-wheels, where these exist, should be distributed equally over the bearings.

Horizontal machines have the advantage that the weight is kept low. The cylinder can be made double-acting with the valves at both ends acting exactly alike; while in vertical machines made double-acting, the operation of the valves at each end would be reversed, the inlets at one end closing with their own weight, and at the other end the weight being against the closing, this being the same with the outlet valves. Horizontal machines can be made of much longer stroke than is practical with vertical machines, thus lessening loss at each end of the stroke from clearance and seating of valves. They may be made with air and steam pistons upon the same rod, which is not practical, or at least not common, with vertical machines, except those having very short strokes. This point, however, is subject to that as to straight line *versus* crank compressors in general. It is claimed that in horizontal machines the water circulation can be more equally distributed than in vertical, and that the water can be carried off without dripping on the cranks and other working parts, and causing an unsightly mess.

Compressors are known as either wet or dry, according as water is or is not employed in the cylinder for lubricating and cooling. Dry compressors had at first the disadvantage that the valve could not be kept tight, and that the valve stems broke from constant slamming. These troubles are now avoided by the employment of rubber discs for valve faces and cushions.

While there is no doubt that the air can be kept cooler in a wet than in a dry compressor, and that the wet will give better results in regard to economy than the dry, still there are advantages in the dry compressors that the wet do not have. Air from wet machines is constantly saturated with water, and more or less water is carried along with the air in the pipes.

In wet compressors there is this advantage, that the piston is exposed to water leakage only. There is the great disadvantage that the heat of compression vaporizes a portion of the water, which is carried through the compressed air and condensed, or even frozen, blocking up the exhaust passages of the rock drills, etc. This watery vapor also reduces the capacity of the compressor.

That class of wet compressors with trunk pistons, in which the inlet valves are in the piston, and the discharge valves at the bottom of the compressing cylinder, and in which water enters with the compressed air into the reservoir, can only be made single-acting, and hence have not come into very general use.

The Sommeiller and Dubois systems have the advantage that they compress the air cool; and they can use leather or rubber valves, which are less liable to accident than metallic valves. These machines are durable, and not so complicated as others, but they have the disadvantage of slow piston speed, as a body of water under pressure of 4 or 5 atmospheres cannot be moved more than about 160 feet per minute without considerable loss of the motive force employed. There is also this disadvantage that the whole weight of the body of water contained in the compressing cylinder has to be lifted at each stroke of the piston

against gravity and an increasing pressure, to replace the volume which the air ordinarily occupied, as well as drawing it behind at the return stroke. It follows that they have to be very large in proportion to the compressors, which with the full supply of air could run with 3 or more times the speed.

Those who are not in favor of conveying all the power through the main shaft, are opposed to it on the grounds that it causes a heavier loaded friction than would be the case if the air and steam cylinder were mounted on the same rod, and only their differences in power and resistance allowed to reach the main journals; that three main journals in line are liable to have a pound or to run hot, and generally are a feature to be avoided.

In opposition to the advocates of applying the steam power at the moment of greater resistance of the air under compression, there are those who claim that this really amounts to nothing, for the reason that if this critical point is balanced then another critical point is created when the steam is near the last of the stroke and has little power, and being near the centre has little command of the crank; then the air-piston is on the beginning of its stroke, has moved some distance away from the centre, has considerable command of the crank, has some air pressure in front of it, and the removing parts are acquiring velocity and are hence calling for power, and at this point the fly-wheels are their only dependence. It is claimed by some that where steam and air pistons are mounted on the same rod any amount of power can be transferred from the beginning to the end of the stroke by simply using proper weight of parts.

It is urged against those compressors having the air-cylinder in close proximity to the steam-cylinder that the inlet air is liable to be much heated, so that a given weight of air will require more power to compress it.

In those types of compressors in which the steam and air-cylinders are on the same line, with the pistons attached to a common rod, it is claimed by some that the steam has to follow full stroke in the steam-cylinder in order to overcome the greatest resistance in the air-cylinder at the end of the stroke of the air-piston.

The advocates of crank compressors claim superiority by reason of the greatest power of the steam-engine being at the point of greatest resistance in the air-cylinder; *i. e.*, at the end of the air-piston stroke. They can also use an adjustable cut-off in the steam-engine, thus using steam economically.

In those cases where the cranks are at right angles to one another the machine is capable of compressing air up to double the steam pressure employed when the steam and air cylinders are of the same diameter and the same stroke.

Duplex crank compressors can be run slowly where desired, as the cranks are placed at right angles to each other, and there is no dead centre.

In air compression, many builders put the maximum admissible clearance between the piston and the cylinder-head at $\frac{1}{16}$ inch, which can hardly be obtained with direct transmission; and with a crank motion can only be done by having some method of adjusting the length of the piston-rod so as to keep the piston working at the same distance from each head.

Pump or plunger compressors are used much in German and Austrian mines, and very much liked, but are little used in the United States. They have the disadvantage that the moving of the large mass of water causes great loss in overcoming inertia, the violent shocks prevent running at high speed, and not only that, but they prevent the prime mover being run at a high speed without costly and power-wasting gearing; they do not generally give pressure above 5 or 6 atmospheres, because the air takes up so much cooling water even at low tension, and the cooling water has very little effect. They have the great advantage that they are simple, have no dead spaces, and cost very little for repairs if run at the speeds for which they are intended.

Single-acting compressors have the disadvantage that they require two compression

cylinders; they require to be driven by indirect methods, hence are apt to be cumbersome and costly, and in some cases the working parts are difficult of access.

The valves of air-compressors require to have large area and small travel; the area is generally from $\frac{1}{8}$ to $\frac{1}{16}$ of the sectional area of the cylinder, and the travel is sometimes as small as ·08 of an inch.

For compressors to be run very fast it is necessary that the valve area be very large.

As regards speeds, these vary from 300 to 500 feet per minute.

The objections to high speed compressors are (1.) that heat is rapidly accumulated in the cylinder. (2.) With dry metallic spring pistons there is loss of air from 7 to 10 per cent, and increasing largely with low piston velocity. (3.) Voidance of air from the cylinder during the closing of the inlet-valves. (4.) Loss of effect of steam by reason of air passing from front to back end of the spring ring pistons. (5.) Rapid wear and tear of parts. (6.) Liability of the valves to break; the force of the blow increasing with the square of the velocity. The disadvantages of low speed compressors are that the piston speed is low, the machine large in proportion, and the first cost high.

Slow speeds have this disadvantage, that they allow the air time to take up the heat of the cylinder, and expand, and thus their capacity in weight of air compressed is limited.

Mr. Robert Allison states as the result of recent experiments made by him, as to the power given out by compressed air at pressures varying from 20 to 65 pounds, the test being made with a compressor driven by a turbine wheel, that with air at 20 pounds the compressor developed 49 horse-power; with air at 40 pounds, 41 horse-power; and with air at 65 pounds, 30 horse-power. In each case the turbine is stated to have been running at full gait, and air allowed to blow off so as to keep uniform pressure at each test. This would show a low-pressure machine to give the best results simply as a compressor, provided the air cylinder is of the proper size. If the air were used expansively the loss would not be so great.

It is very desirable that there should be some method by which the amount of air furnished should be directly proportional to the consumption by the drills or other utilizers of compressed air. If possible, it is in most cases desirable that the consumption of steam and of fuel, or of other motive power, should also be directly proportional to the air consumption. To effect the regularity in the reservoir there are several methods employed. By one of these pistons the compressor runs at a certain fixed speed, which is made sufficient for the greatest requirements of consumption. If the drills are stopped or the other air consumers thrown off for any length of time, then the pressure rises in the reservoir until relieved by the safety-valve, which allows the air in excess of requirement to blow off into the atmosphere, the compressor ceasing in its action and yet lessening its steam consumption.

In another system, there is a proper valve closed or opened by the pressure in the air reservoir. Under this system the air-governor shuts off the steam and stops the compressor. By this method steam is not employed when all the drills are thrown out of use. There may be urged against this system, which instead of keeping the machine in constant motion consuming steam, stops it entirely, that it may not be ready for a sudden exhaustive call, and the steam-cylinder will be allowed to get cooled and give trouble with water of condensation.

By another system, there is a lever controlled by the air pressure in the reservoir, which lever lifts the suction-valves from their seats when the air pressure in the reservoir reaches the desired limit, thus allowing the air to blow back into the atmosphere, all load being thrown off the compressor, which is prevented from running away by an ordinary throttling steam-governor.

This, again, is open to the objection that it is wasteful of compressed air. In the distance to do away with the disadvantages of those above mentioned, the air discharge pipe connects with the boiler or steam pipe, and in this connecting pipe there is a valve so regulated that whenever the air pressure rises above a predetermined point, this valve will open and allow the surplus air to escape into the steam. This excessive air, for the time being,

drives the machine and saves a certain volume of steam. By this system, when all the drills work, the compressing cylinder acts as a steam-engine pure and simple; when part of the drills work, it is an aero-steam-engine; when all the drills are stopped, it is an air motor engine. This system is open to the objection that it cannot be used in those cases where air of a lower pressure than that in the steam-cylinder is desired.

In regard to regulation, some propose that the air and the steam cylinders should be so proportioned to each other that at no time should the air be forced up to a pressure above that of the steam, and then by using a duplex machine it would regulate itself; when the resistance of air was too much for the steam the machine would slow up or stop, and as soon as the air pressure was drawn down, the machine would start up slowly, and its speed would be regulated by the quantity of air used.

It is claimed that compressing cold air instead of warm gives a gain. Considering the temperature of the air throughout the year in the Northern States to be 62 degrees, and the average temperature of engine-rooms 82 degrees, the advocates of taking cold air instead of that which has been warmed by a steam-cylinder and steam-pipes, claim that it takes from $3\frac{82}{100}$ to $4\frac{1}{3}$ per cent more power to compress a given weight of air at 82 degrees to 60 pounds than to do the same work upon air at 62 degrees.

The low-pressure cylinder will have, say 100 square inches of area, and the high-pressure $33\frac{1}{3}$. In forcing from the large cylinder into the small one, the air is given (nearly) 30 lbs. per square inch tension, by the gauge. The resistance equals (roughly) $66\frac{2}{3} \times 30 = 2000$ lbs. On the return stroke, forcing from the small cylinder into the reservoir, the air at 30 lbs. per square inch in the small cylinder is compressed to 100 lbs. per square inch; the greatest resistance in the small cylinder being $33\frac{1}{3} \times 100 = 3333\frac{1}{3}$ lbs. This, added to the 2000 lbs. resistance of the first stage of compression, shows a total resistance of $5333\frac{1}{3}$ lbs. Had the large cylinder only been used to effect compression to 100 lbs. per square inch, at one stroke, the resistance would have been 10,000 lbs., or $46\frac{2}{3}$ per cent greater. By having all on one heavy cross-head, the momentum stored up is given out when the steam gets weak. The air discharge valves in a single cylinder compressor have the full receiver pressure more than half of each revolution. In the compound the heavy pressure is upon small valves only. To lessen the effect of clearance there are two ways of doing; the stroke may be made long and the piston run close, which is expensive, and requires careful watching, or the space may be filled with water, which prevents high speed, as the water gets churned to a foam, besides making ice in the exhaust of the drills or other machine using the air. The water-jacket has not time to fully cool the air, even if it were not rapidly covered by the advancing piston; but it is a valuable auxiliary.

There are many who think that while stage-pumping is highly desirable for pressure above 80 pounds, simple compression in any one cylinder answers all purposes and gives the best satisfaction for pressures below 80 pounds.

Those who use injection water claim that by so doing they not only cool the air but lubricate the cylinder and discharge a little with the air, which, forcing the air ahead of it, insures a complete expulsion of all the air after compression.

Water-jackets on the sides and heads of the cylinders and the pistons have the advantage that they deliver dry air. They have the disadvantage that if the speed of the compressor be great, the time of contact of the air with the cooling surfaces is necessarily limited, being less than one second.

In reference to the lubrication of the air-piston, it is argued by some that it is absolutely necessary to inject water into the air-cylinder for lubrication, or to have an annular space in the piston kept full of water to lubricate the walls of the cylinder. But it has been found by some builders and users of dry compressors that with gun-metal rings in the piston, simple lubrication with oil will keep the cylinders in first-class condition. This, of course, requiring that the walls of the cylinder are kept cool.

There is this advantage in closing the valve at the centre of the stroke, that at this time the crank is almost upon its centre, and the motion of the rod is at its slowest; thus the valve may be brought to its seat gently and without any violent concussion.

In some machines the inner surface of the discharge-valves are rounded off so as to present an opening as nearly as possible approaching the form of the *vena*, and thus while giving large capacity, reducing the friction to a minimum.

It is claimed by those who employ positive moving valves, that with poppet-valves in the cylinder-heads operated by springs, these latter lose their elasticity, and fail to operate, when the cylinder does not get completely filled with free air, causing a reduction in the amount of compressed air.

There are cases in which positive moving valves may not give satisfaction. By reference to the indicator card *A* (p. 176), it will be seen that at the moment of closing the inlet-valve the vacuum was $8\frac{3}{4}$ pounds, and the pressure in the cylinder did not reach atmospheric pressure until it had advanced about one-third of the return stroke. In this case the positive slide cut off all communication with the atmosphere at the end of the stroke.

It is claimed by those who prefer poppet-valves, that if a poppet had been used, and even if its area had been as restricted as the slide, more air would have got into the cylinder, because the poppet would allow the air to pass even after the piston had turned and was coming back.

It is further urged against the positive motion valve that while the air in the clearance space should be held entirely by its expansion, it return the power used in compressing it, a valve-opening, say, on the centre, will allow air in the clearance space to be exhausted. Of course, clearance spaces will always exist in dry compressors. If the positive opening-valve were to open later than on the centre, it is further argued that the proper time of opening (which is when the air in the clearance space has expanded down to atmospheric pressure) would vary with every change of pressure in the reservoir, and would require complicated mechanism.

The trouble with compressors in which the opening of inlet-valves depends upon the formation of a vacuum in the cylinder during the backward passage of the piston, is that their action may be more variable, except at a very slow speed, the action of the inlet-valves becoming fitful and irregular, and the quantity of air compressed per stroke diminishing. The compressed air in the clearance space and the valve passages adds to this difficulty, as it has to be drawn down to atmospheric pressure by the backward movement of the piston before the vacuum required to open the inlet-valve begins to be formed, thus delaying the opening of the inlet-valve until late in the stroke.

There is in some compressors generation of heat by the friction of the air in being driven through delivery passages of too contracted area and improper form and position. There is friction of the particles of air among each other in those cases where the delivery is at right angles with the motion of the piston.

Concerning positive or air-lifted valves, many builders think that for inlet-valves there cannot be much difference between them, but for outlet-valves there would be considerable advantage if the valves were operated positively, just when the air in the cylinder reached the pressure in the reservoir or the pipes, but as this constantly varies, and would require the valves to be opened at different points in the stroke, it would be a difficult matter to arrange for this variation. But the outlet-valves could be arranged in such form as to be balanced, and then by closing them positively when the piston reached the end of the stroke, they would be lifted when the air-pressure was equal on both sides. There is this much certain, that any arrangement of valves, whether positive or air-lifted, which leaves any quantity of compressed air in the passage or pockets, detracts largely from the capacity of the machine, and should for many reasons be avoided.

In America, air-compressors were applied first for purposes of rock-drilling at the Hoosac Tunnel. Previously, however, attempts had been made to apply compressed air for various purposes.

The first compressor used at the Hoosac Tunnel is shown in Fig. 68. It consisted simply of four horizontal air-cylinders, run by a turbine-wheel of 120 horse-power. The pitman was connected directly with the crank on the upper end of the shaft of the turbine. Of this

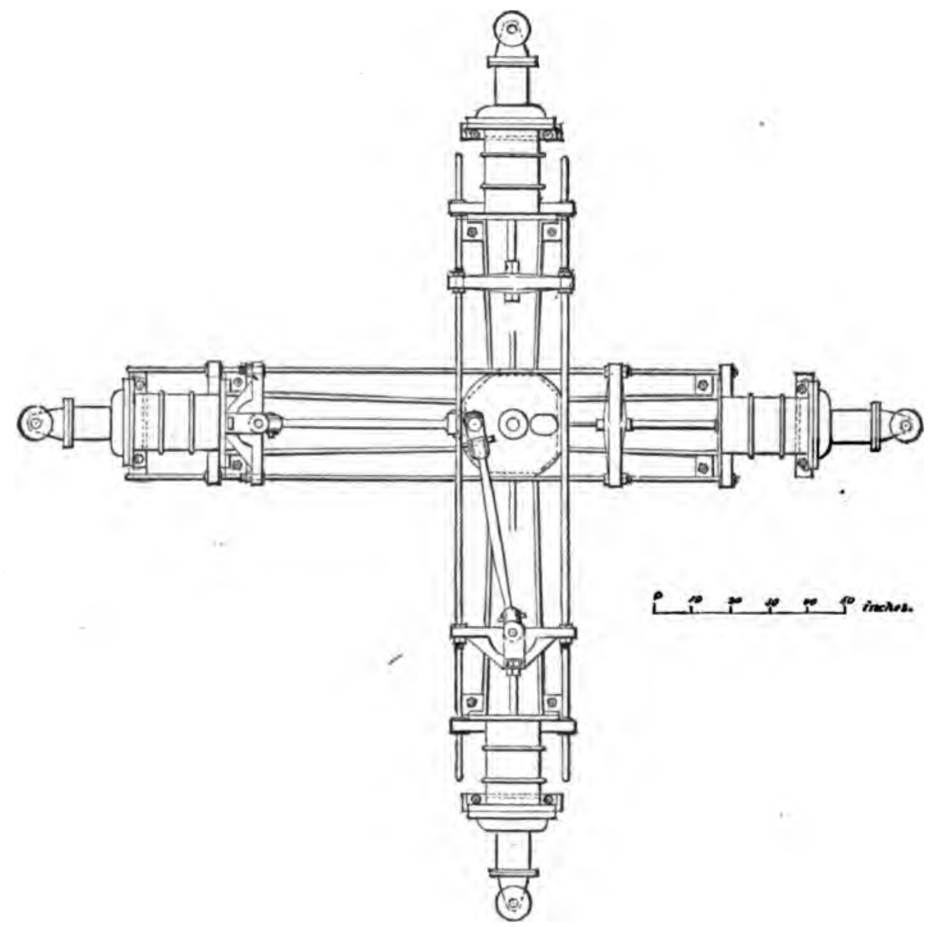


FIG. 68.

PLAN OF AIR-COMPRESSOR, NO. 1, HOOSAC TUNNEL.

compressor, Mr. Thomas Doane, chief engineer, says in his report for 1866:* "The air-compressor of four horizontal cylinders, 13 x 20 inches each, referred to in my former report† as about ready for use at the East End, has been at work night and day without cessation, except on Sundays, since March. It was intended to compress air to 60 pounds per square inch, and has run it up as high as 85 pounds; but as the drilling-machines require air at only 30 pounds pressure, it has generally been run at that pressure. It was intended for a speed of 120 revolutions a minute, but as it can easily supply all our drilling-machines, nine having been the highest number, at a speed of 70 revolutions, it has not usually been run faster. This compressor, making 70 revolutions, will furnish 148·01 cubic feet of air per minute, at a pressure of 42 pounds." Another compressor of this same style is shown in

* House, No. 30, p. 17 (Massachusetts Legislative Reports, 1867).
† House, No. 4, p. 21 (Massachusetts Legislative Reports, January, 1866).

Fig. 69. The cylinders were 25 inches in diameter by 24-inch stroke; the machine was run at low pressure, and only used to supply air for ventilation. Both these compressors remained in use at the east end of the tunnel until the work was completed, seven years in all. These four cylinder (horizontal) compressors, driven by a turbine, were originally designed under the

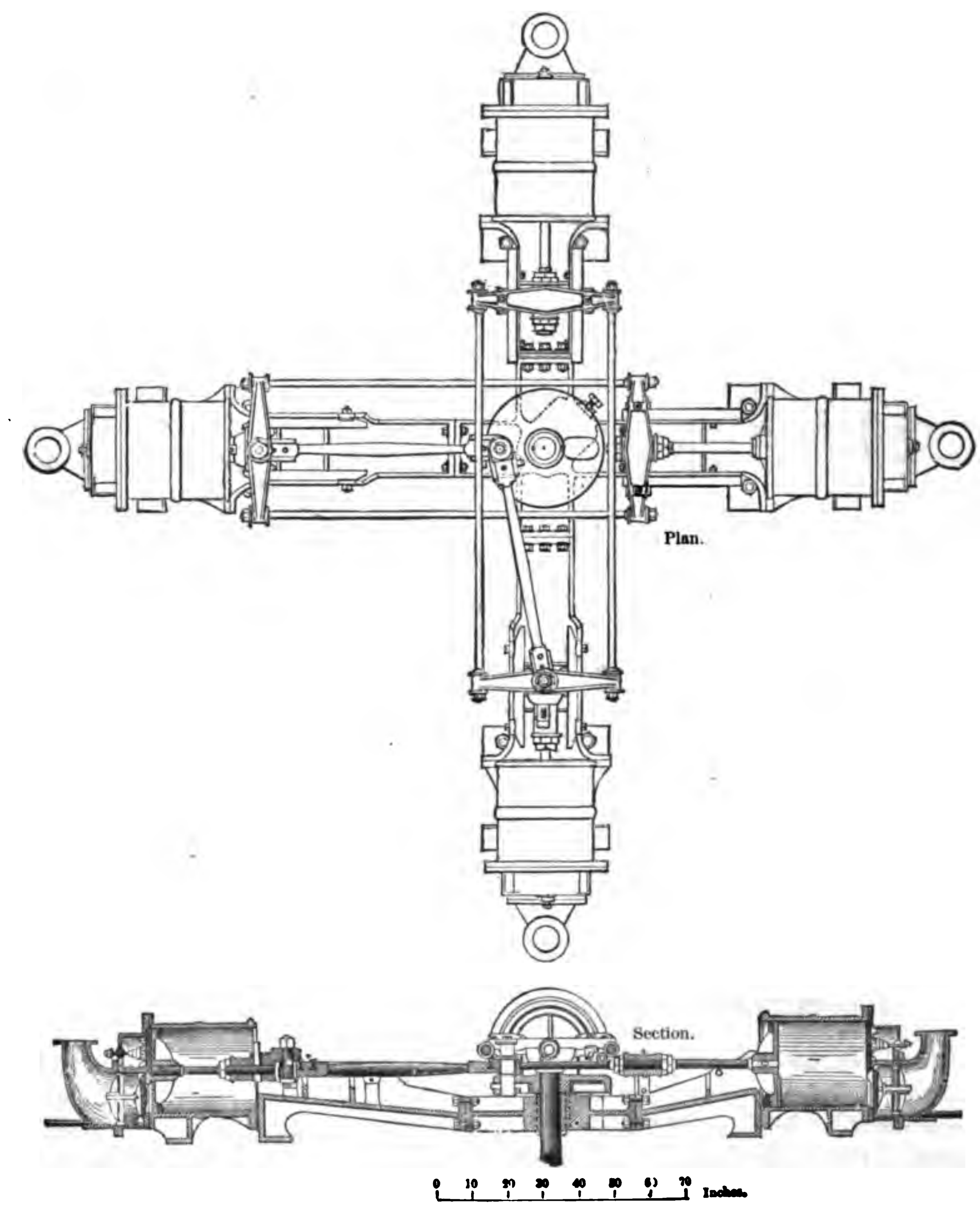


FIG. 69.

PLAN AND SECTION OF AIR-COMPRESSOR, NO. 2.
Designed for supplying air at low pressure for Hoosac Tunnel, 1866.

direction of the Massachusetts State Commission, of which Mr. John W. Brooks was chairman. Mr. Thomas Doane, chief engineer of the tunnel at the time, had the experiments in charge; he was assisted by Mr. John Christiansen. To Mr. Doane is chiefly due the larger

share of the credit for the persistent efforts made by the commission to develop practical rock-drilling machinery. He originally invented many points connected with such machinery, for some of which he holds patents; others were allowed to pass without patenting.

It is curious now to note some of the early expedients that were devised. For instance, to cool the cylinders in the above four way compressors, Mr. Doane, in 1866, hung a flexible rubber tube from a water-pipe passing above the compressor, and from this pipe water was injected through the piston into the cylinders, by an aperture about the size of a knitting-needle. As soon as this jet was introduced, the temperature of the compressed air dropped from 300 or 400 degrees to about 5 degrees above its original temperature before being drawn into the cylinder.

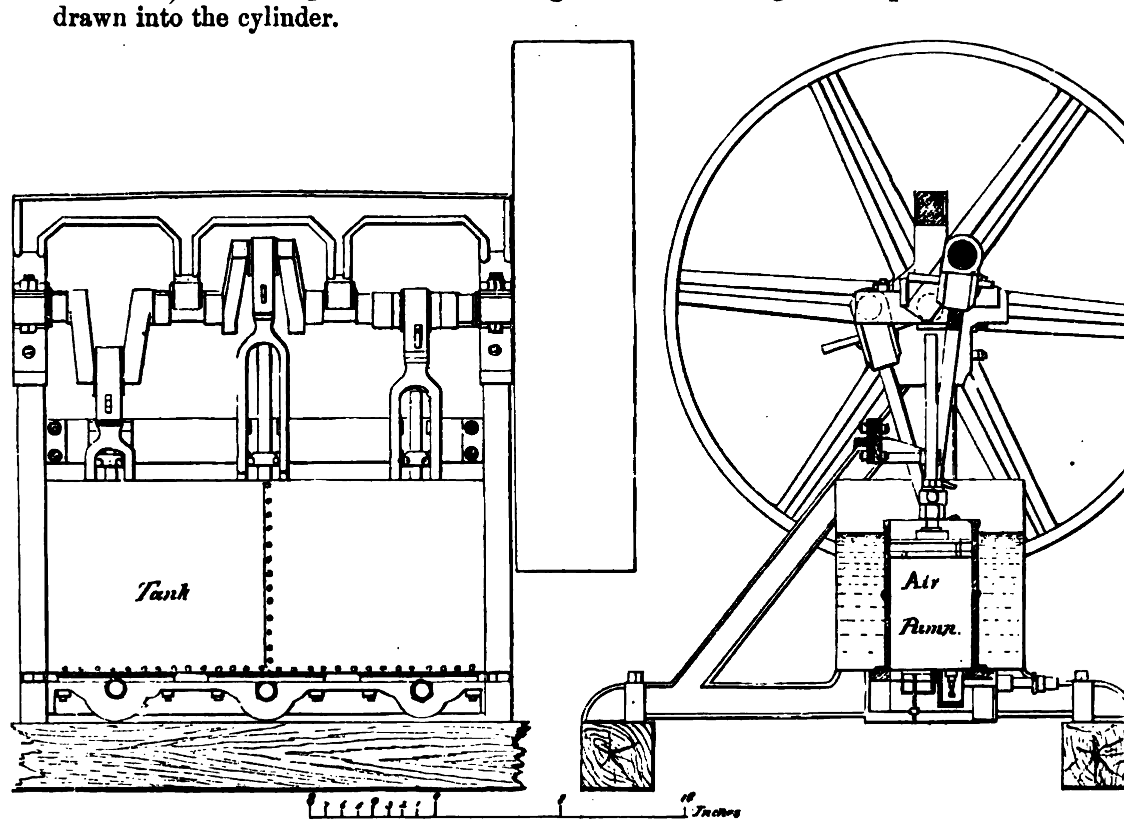


FIG. 70.

AIR-COMPRESSOR USED EXPERIMENTALLY AT HOOSAC TUNNEL.

Fig. 70 shows another early compressor, with three vertical cylinders of 8 x 12 inches stroke; it was used for experimenting at Hoosac. Fig. 71(*a*) is again another that was patented December 31st, 1867, by Mr. Doane; it remained in use throughout the construction of the tunnel. Fig. 71 (*b*) shows an application of Mr. Doane's valve in a compressor manufactured in 1877 by Guild & Garrison, of Williamsburg, N. Y. (See the "Scientific American," New York, May 19th, 1877, for fuller description of this compressor.)

In the section of the valve, Fig. 71(*b*), A is the air-cylinder, B is the piston-head, C is a side of the tank attached to hold water for cooling the cylinder A; *d* is a pipe for taking the air after compression into the receiver; *e* indicates the spring around the valve-stem to keep the valve up to the cylinder end; *f* is the oblong free-air opening to secure complete filling of cylinder before compressing the stroke; G is the valve lifted slightly from its seat, and sitting upon the piston-head; *g* is the hub connecting driving-pin with piston; H is the

chamber into which air after compression is forced, and from which it is taken away by pipe d; I is a valve-opening in the cylinder-head on the return stroke, and permitting air to enter cylinder before the piston-head passes the free-air part f; J is the piston, having a head on both ends, and entering both air-cylinders; K is the pin connecting with the engine's driving-rod.

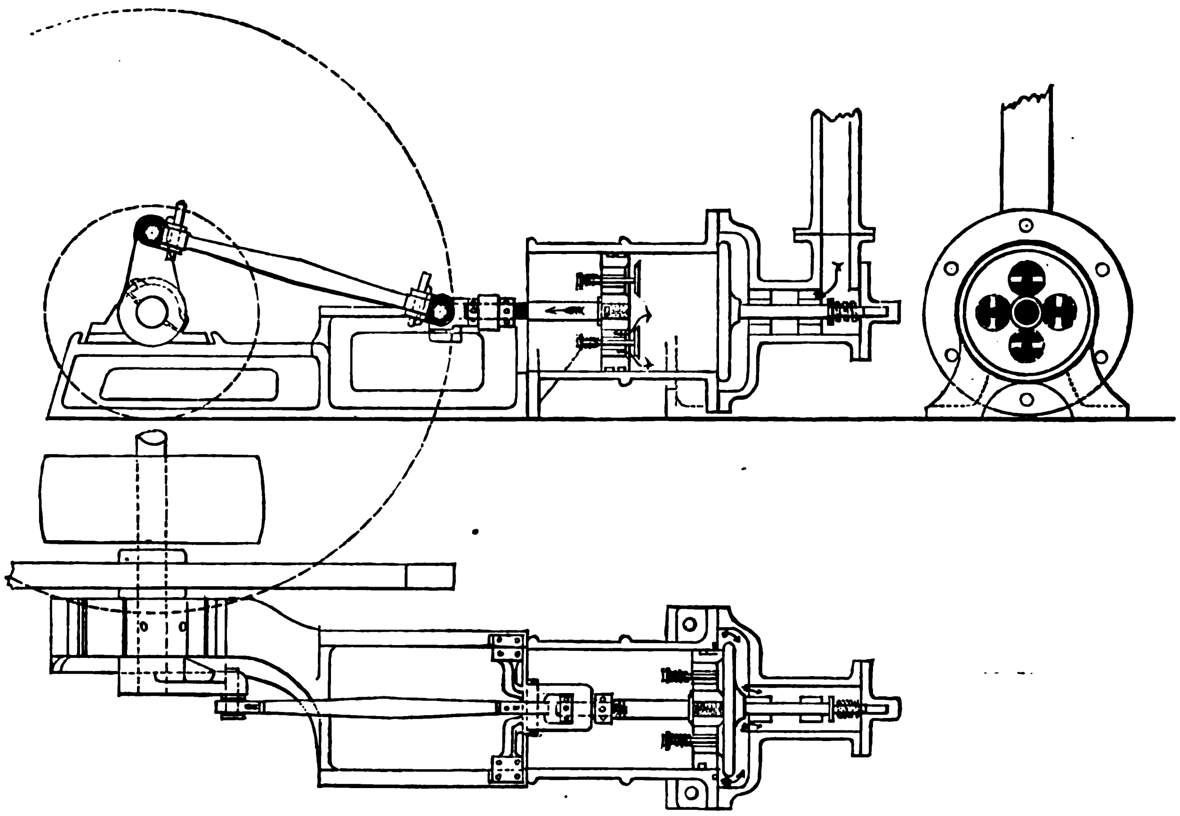


FIG. 71(a).

THOMAS DOANE'S IMPROVEMENT IN AIR-PUMPS.

Patented December 31st, 1867. Tried at Hoosac Tunnel, and used to the end of the work (*i. e.*, for seven years). Scale, [illegible].

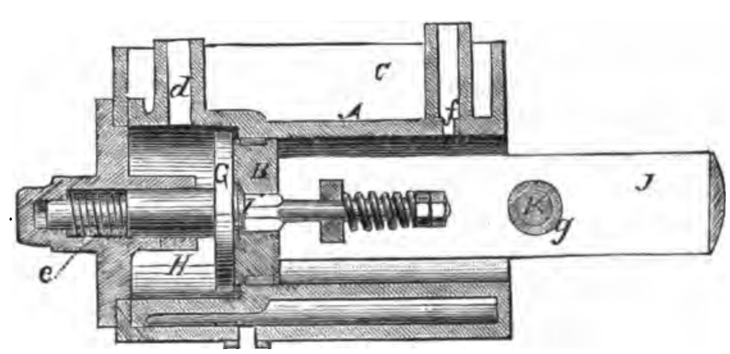


FIG 71(b).

The Burleigh "two-drill" compressor, as at first manufactured, is shown in Fig. 72; (a) was the form of valve first used, where a stem was used to guide the valve instead of a sleeve, as in (b). This type (b) was used at the Hoosac, Nesquehoning, and Musconetcong tunnels and

gave satisfactory results. Those used at Musconetcong were the same ones that had been used at Nesquehoning, being purchased by Mr. Charles McFadden, contractor for Musconetcong Tunnel, from the Lehigh Navigation Company, on the completion of the Nesquehoning work.

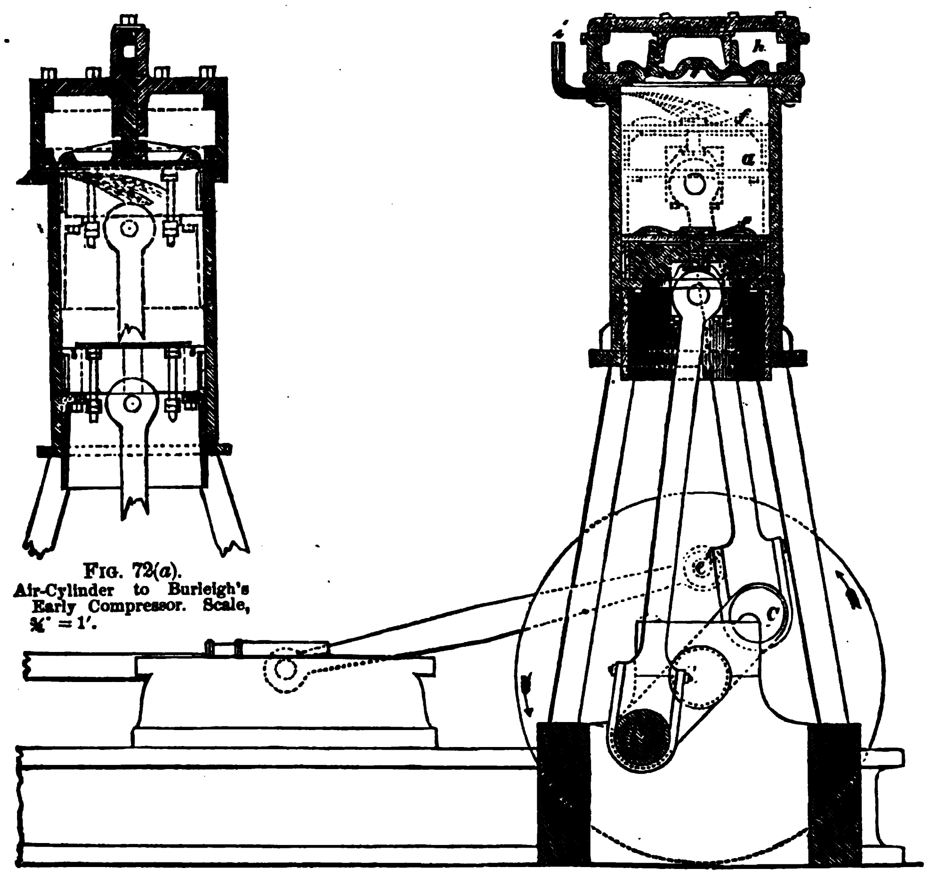


FIG. 72(a).
Air-Cylinder to Burleigh's Early Compressor. Scale, ¾" = 1'.

FIG. 72(b).
BURLEIGH COMPRESSOR AS FIRST MADE, WITH HORIZONTAL ENGINE.
Scale, ¾" = 1'.

Four of them did the entire work of running the nine drills at the west end of Musconetcong Tunnel, and did it well.

In Fig. 72(*b*), it will be seen that the pistons (*a*) of the air-cylinders are worked from a shaft, the cranks *b* and *c* of which are at an angle of 180°. With these the motor-crank *e* forms an angle of 45°, so that the greatest work of the motor-piston is designed to correspond with the greatest resistance offered to the compression piston. The valves *f* and *g* are circular plates, held in place by vertical guides. The compressed air from the two cylinders is driven into a common chamber *h*, and thence conducted by pipes to a receiver, which serves to insure an equalized pressure, and from the bottom of which any water carried over by the air and condensed is tapped at intervals. This water is admitted in a jet through the pipe *i*, and serves to cool the cylinders, and, in working down, assists also as a lubricator. To furnish steam for the four compressors at Musconetcong, four return tubular boilers, of 45 horse-power each, were used. The compressed air was conducted by a six-inch pipe, at first about 1300 feet, and, before the headings met, about 3000 feet, before reaching the drills, and it was observed that the loss of pressure rarely exceeded more than two to three

pounds, and generally was less. It will be observed that the air-pumps of this machine are arranged in an inverted position, the advantage of which is that the valves drop by gravity in closing, and the air is compressed on the upward stroke of the piston, the water which is injected for cooling the air also serving for a perfect packing by lying upon the piston, thus preventing any leakage of air during compression, and also acting to expel all air between the piston and the upper valves. This compressor is of interest as being the first to attain general prominence in America. It was soon modified by having the steam-piston placed vertical instead of horizontal. Also, of late, the Burleigh Company have been making their compressors much heavier than at first.

Fig. 73 shows one built in 1876. Its capacity was 880 cubic feet of air per minute.

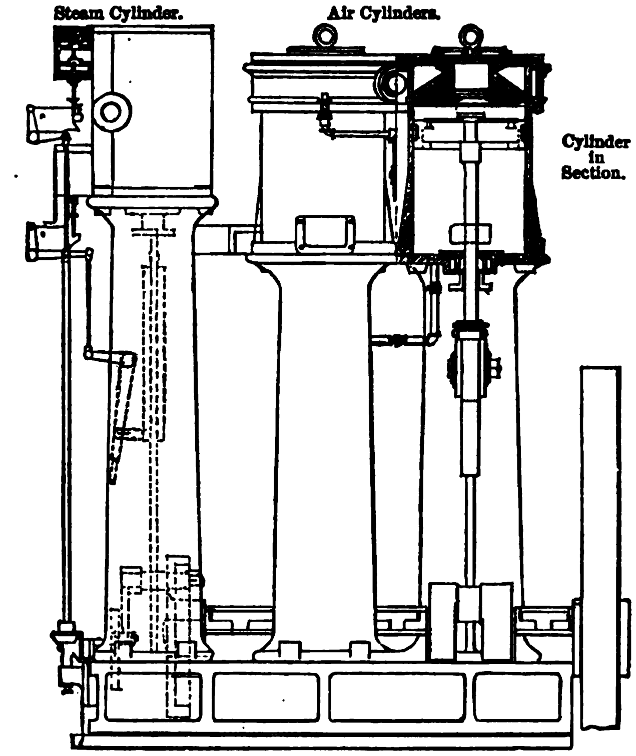
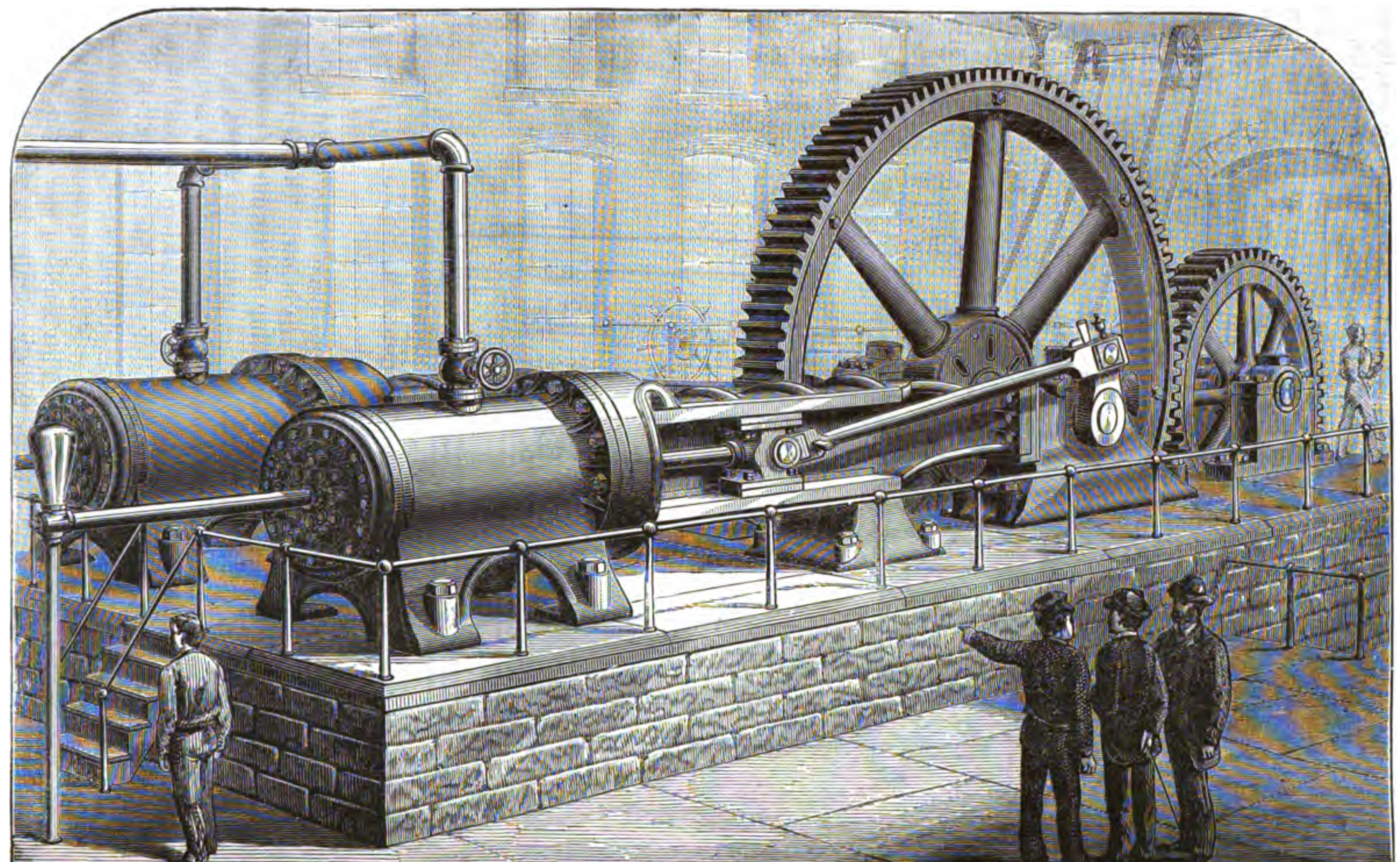


FIG. 73.
IMPROVED LARGE BURLEIGH COMPRESSOR.
Scale, $\frac{1}{48}$.

The difference between this and the older styles is, that the air-cylinders are closed at the bottom, which prevents the water dripping upon the working parts below. The air is admitted to the cylinders through ports on their sides. Water for cooling the air during compression, and for packing the piston, and to fill all vacant space between pistons and valves, is injected in the same manner as in the old style of machines. The air-cylinders are arranged in such a manner that the pistons and valves can be removed without taking the machine apart. The engine of this machine differs from the earlier styles in this respect: it is constructed with an improved balance poppet valve gear and graduating cut-off, the advantage of which is the saving a large amount of fuel. The cubic feet of air compressed is nearly equal to the cubic feet of steam used in the steam-cylinder. This machine also differs from the older forms in having crossheads and guides under the air-cylinders in place of the trunk-piston, the advantage of which change is the prevention of tendency to wear the bore elliptical. (See p. 158.)



RAND DUPLEX-GEARED COMPRESSOR, 1881.

In the Rand duplex horizontal dry compressor of 1881, the steam-cylinder has poppet-valves and variable automatic cut-off; the cylinders are side by side, bolted to the same bed-plate; crank quartered (see figure above; also page 157). There is water circulation through piston and cylinder heads and around the cylinder, the cylinder having three shells, forming two annular spaces around the working cylinder. The outer space is for the air after compression, and the middle one for water circulation. The air tank receives air at one end, and the discharge is through a safety-valve at the other.

Fig. 74 shows the Rand & Waring compressor of 1876. As will be seen, it consisted essentially of a horizontal air-cylinder, run by an oscillating steam-cylinder. Four of these machines also were used at the Musconetcong Tunnel, being located at the east end, three of 12-inch and one 16-inch air-cylinder. At one time (about 1872–'74) they came into very prominent notice, some of them being sent, some years since, to Henry Meiggs, in Peru, to be used on his contracts there. They, however, cannot be said to have met with general favor.

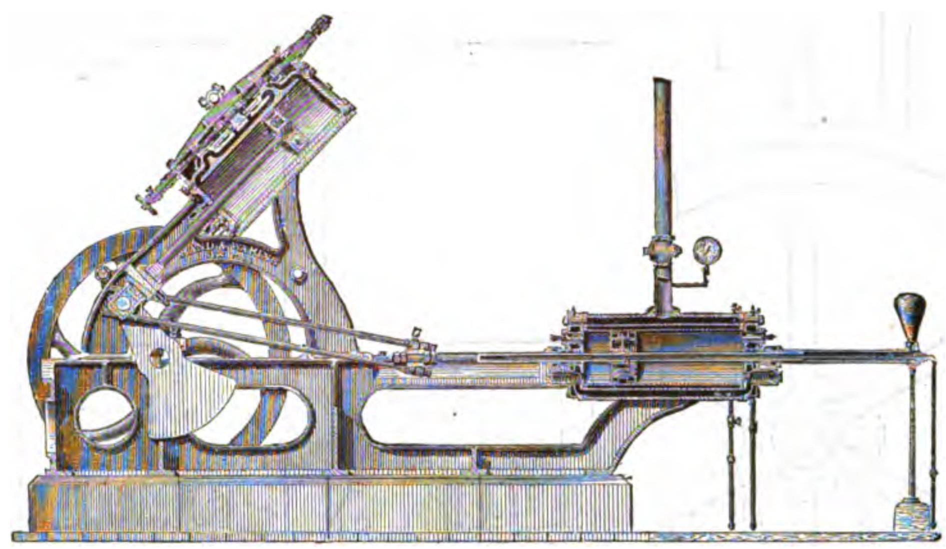
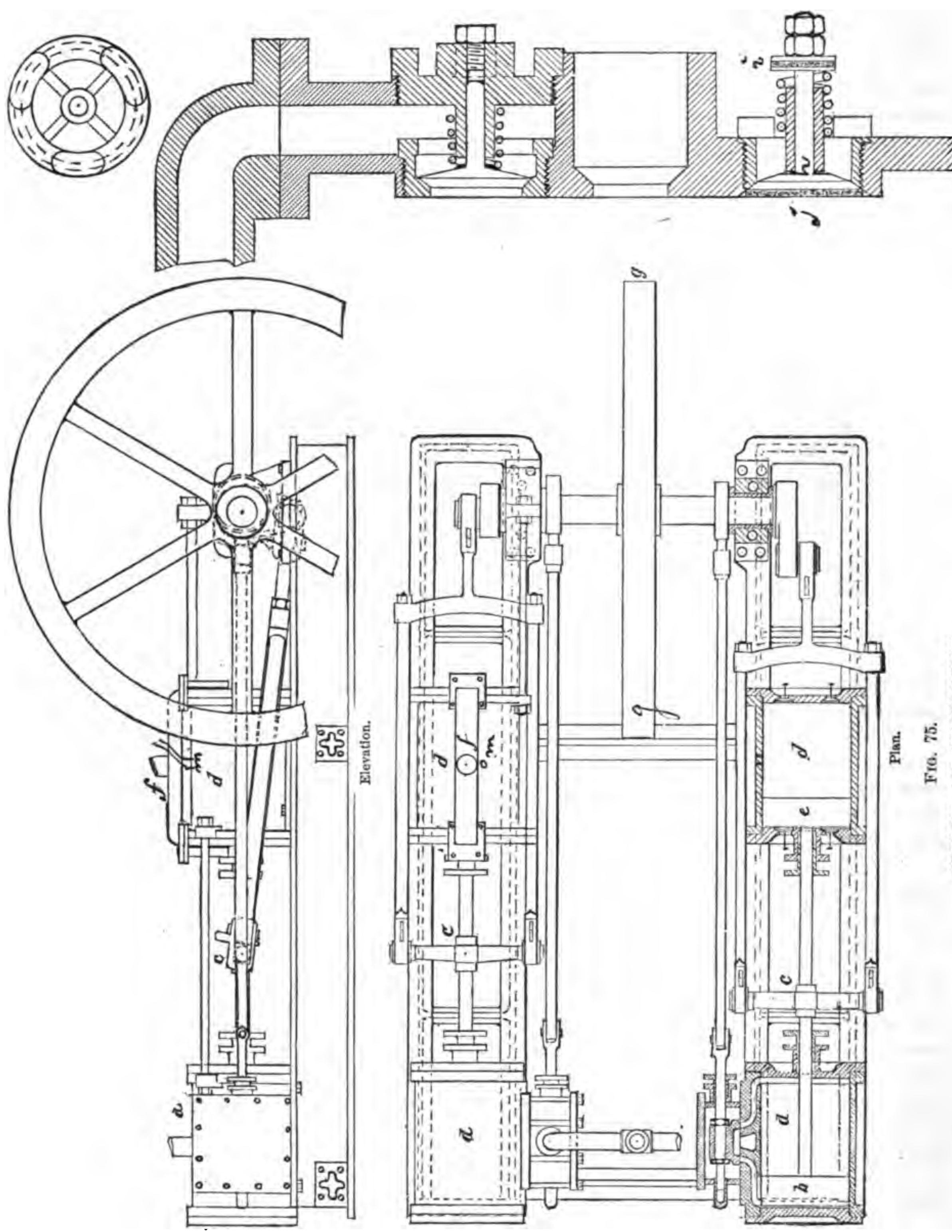


FIG. 74.
RAND & WARING COMPRESSOR.

The oscillating cylinder involved a complication of parts, and, like most new machines, the breakages were found to be too frequent for economical working.

There has been a type of horizontal direct-acting compressors made (in 1876) for the Waring Rock Drill Company, by Alison & Bannan, of Pottsville, Pa. In these the air is cooled by water passing spirally around the air-cylinder, while in the old oscillating Rand & Waring compressor, Colladon's system was used. A number of these machines are in use in the collieries of the Philadelphia and Reading Coal and Iron Company.

Fig. 75 shows Wood's air-compressor, A being an elevation, and B a plan; C is a section of the head of the compression-cylinder. This is a duplex compressor of the class called *dry compressors.* The steam and air-cylinders are in the same line, and, on the respective sides, are connected by a common piston-rod. The cranks are placed at right angles to each other, so as to avoid a dead centre. *a a* are the steam-cylinders, and *d d* the air-cylinders. When the air-piston of one cylinder is near the end of its stroke, the resistance of the air will be greatest; but steam having been cut off from the steam-cylinder on that side, the steam in the other cylinder must complete the stroke. The full pressure of steam being in the other steam-cylinder, and its crank being at right angles with the former one, it will work at an advantage for this purpose. One difficulty experienced with dry air-compressors is in keeping the valve tight, and in the breakage of the valve-stems. The former difficulty is overcome by securing a disc of rubber *j* to the face of the valve *h* projecting a short distance outside of the metallic disc of the valve. By being placed on the face of the valve, there should be no danger of its being crushed by the pressure of the air; and yet the pressure of the air will force the edges of the rubber against its seat, and prevent leakage. The breakage of the valve-stem is prevented by



Section of Head of Compression-cylinder.
Scale, ¼ size.

FIG. 75.

WOOD'S AIR-COMPRESSOR.

Scale, ½" = 1'. (a), Steam-cylinder. (b), Piston. (c), Cross-head. (d), Compression-cylinder. (e), Piston. (f), Delivery-pipe.

placing a rubber disc, or other elastic body, *i*, so as to prevent concussion as the valves are forcibly opened. The inventor holds that, according to experiments which he has made, a water-jacket will reduce the heat in the compressing cylinder but a small amount, and the experiments of others show that, in the wet compressor, the cooling of the air as it is being compressed is due mostly to the wet walls of the cylinder, and not to the body of the water. He therefore injects a spray of water, which has been proved to be the most effectual way of keeping the heat at a low temperature. In the smaller machines, water is admitted at the middle of the cylinder at *m*. This not only cools the air, but lubricates the cylinders. The arrangement is such as to make a compact machine. Several are doing good work in the mines of Colorado and Nevada.

There was an essential difference between the American and European type of compressors built during the ten years from 1866 to 1876. The European type was invariably heavier and larger, and for this reason they were credited, on an average, with lasting longer, and needing fewer repairs, as their solid construction rendered them less liable to small breakages. The policy of building larger compressors, however, is now gaining strength in this country, as mining and railroad purchasers begin to understand the matter better, and to see that greater economy is ultimately attained in purchasing the more expensive, because heavier, early plant.

It would have been impossible, however, in the early days of compressor construction in America, to have introduced the heavy type, as the cost would have condemned it. At the Sutro Tunnel, M. Sutro, at the time of beginning his work, with the sagacity that is characteristic of the man, saw this point at once, and instead of purchasing American compressors, saw and inspected the foreign makes, while abroad, and purchased two of them: one—Fig. 76, (*a*) (*b*) and (*c*)—from the John Cockerill Company,* at Seraing, Bel-

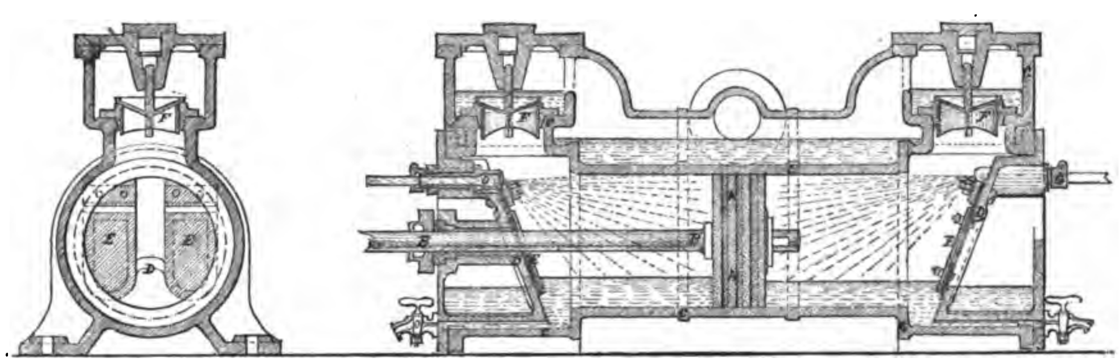


FIG. 76(*c*).

DUBOIS-FRANÇOIS COMPRESSOR.

Enlarged Section of Air-Cylinder [*b* in Fig. 76(*a*)].

A, Piston for double-acting compressor. B, Piston-rod. C, Body of the compressor. D, Cylinder-bottom holding valves. E, Suction-valves. F, Delivery-valves. G, Water-injectors.

gium; the other from the Humboldt Company, at Kalk, near Deutz, on the Rhine—Fig. 77, (*a*) and (*b*). One of these compressors running at a time has been found quite sufficient for the six heading drills; and M. Sutro wrote the author (May 22d, 1877): "We are still making our compressed air at shaft No. 2, for which the compressor of the Humboldt Company, at Kalk, is used. The Cockerill compressor still remains at No. 1 shaft. It is not

* An article on the Dubois-François compressors, with sectional drawings, etc., will be found in "Engineering," vol. xxi., p. 249.

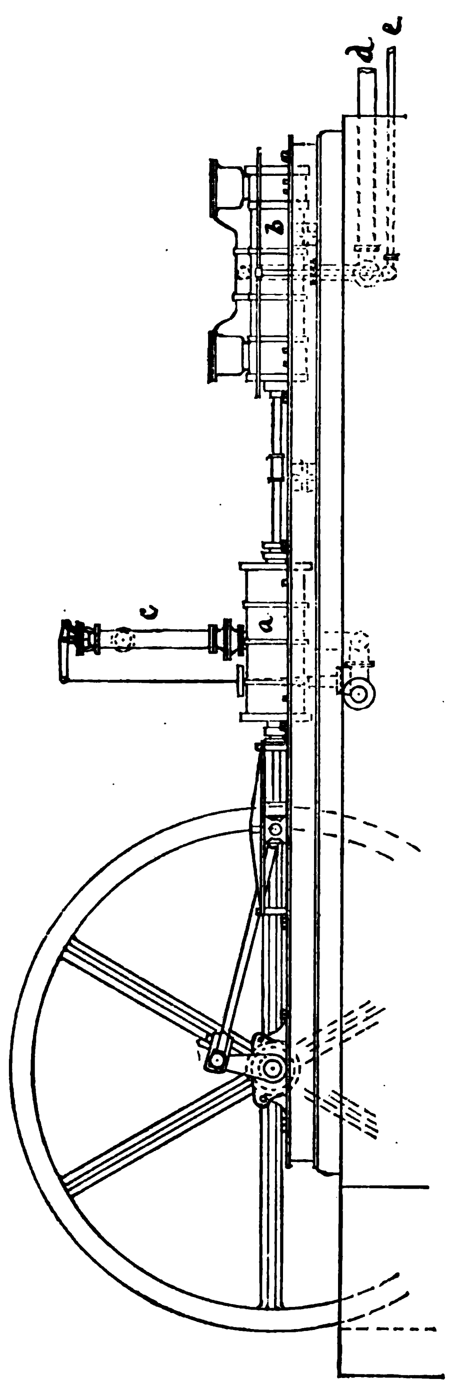


FIG. 76(a).

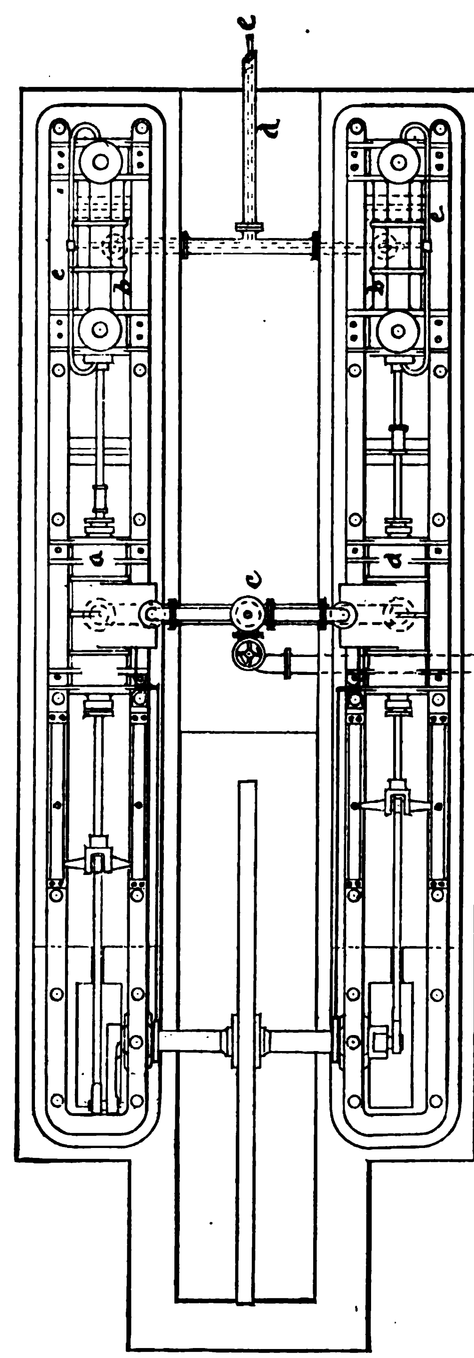
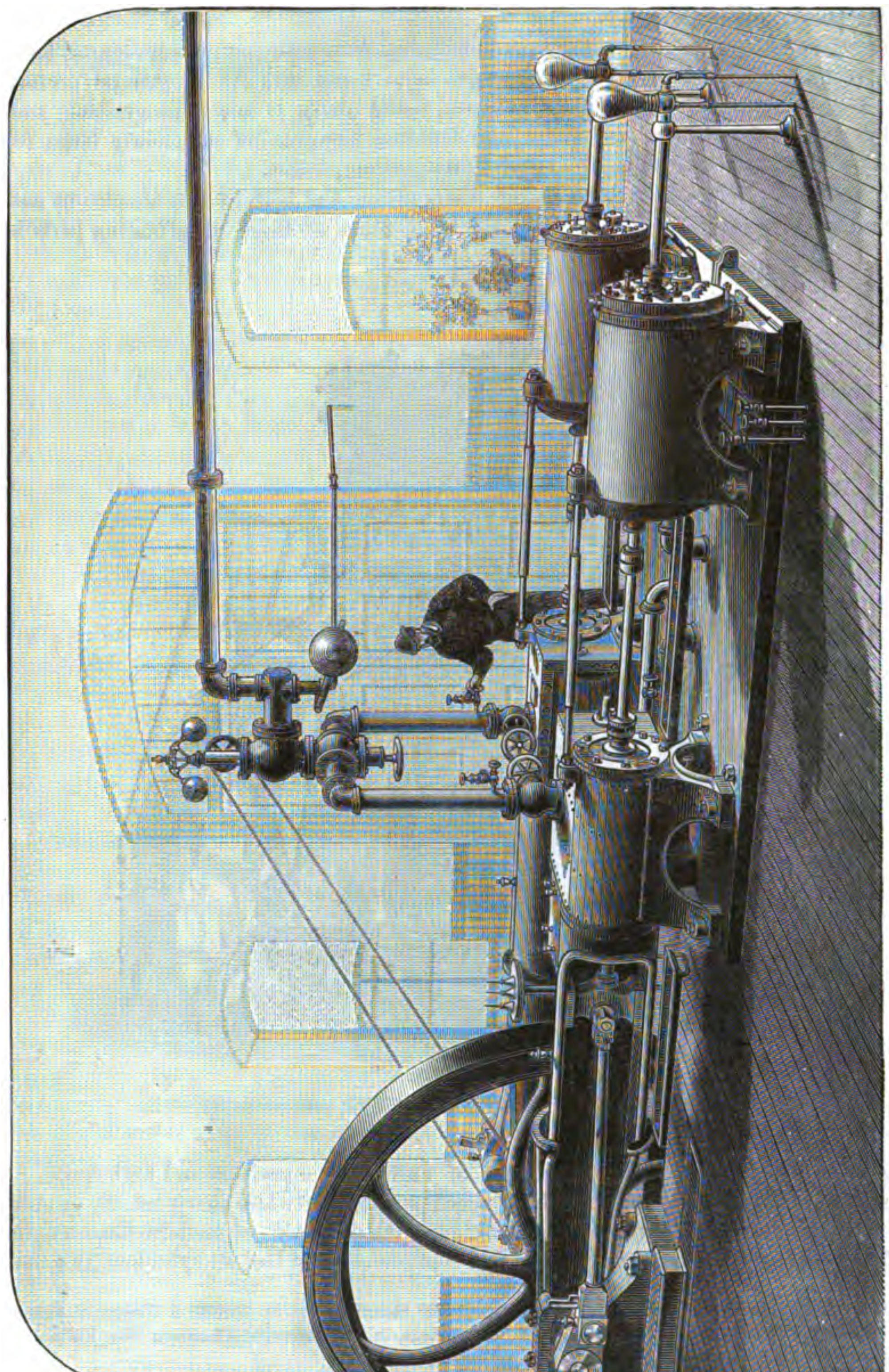


FIG. 76 (b).

DUBOIS-FRANÇOIS AIR-COMPRESSOR.

(a), Steam-cylinder. (b), Compression-cylinder. (c), Steam-pipe. (d), Delivery-pipe elevation and plan of Dubois-François. (e), Water-pipe air-compressor. Scale, $\frac{1}{40}$.

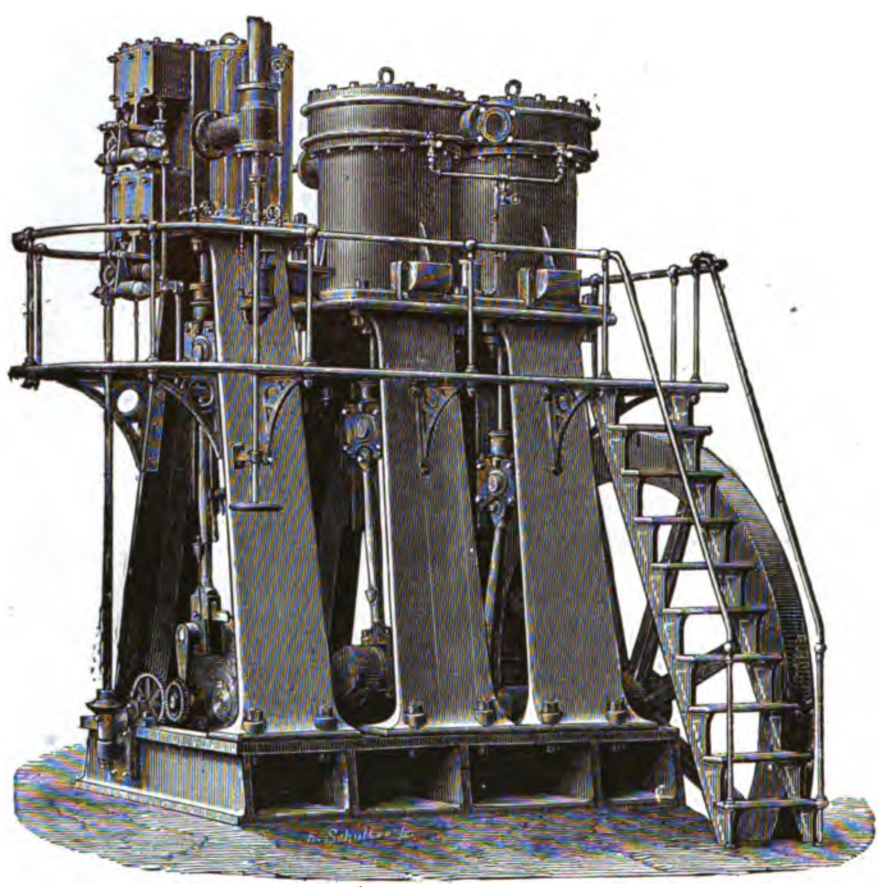


RAND DUPLEX SELF-CONTAINED COMPRESSOR, 1881.—(See page 153.)

used for the present, but will be again after a while, when it is placed at the mouth of the tunnel, where I intend to remove it." *

Of course the only reason for not manufacturing American compressors larger, has been that there was no market for them, the cheaper ones being hitherto in general preferred.† The change of opinion in the public, however, noted above, is surely progressing, and the Burleigh Company and the others are now building compressors sufficiently large for all purposes. The cut below shows the latest Burleigh Compressor.

In the South Norwalk compressor the steam-piston and both of the air-pistons and the crosshead are mounted on the same rod, the momentum of these reciprocating parts being



"No. 7" IMPROVED BURLEIGH PATENT AIR-COMPRESSOR.

largely relied upon to aid in the attainment of uniform compression and high speed. The engine itself is designed to work at a high speed and an early and sharp cut-off, in order to realize the economy attendant upon the adoption of the principles of modern steam engineering. The principal feature, however, is the compounding of the air-cylinders, two double-

* A compressor somewhat similar to the Humboldt was manufactured by Griffith & Wedge, of Zanesville, Ohio, under Bowers' patent. It is described, with illustrations, in the *Scientific American*, New York, July 14, 1877 (vol. xxxvii., New Series, No. 2, p. 15). It is no longer made.

† The illustrations, both of the John Cockerill and of the Humboldt compressors, were furnished directly to the author from abroad by the courtesy of the companies respectively.

acting cylinders of unequal diameters being placed in line, so that the air compressed partially in one can be delivered into the other in order to be brought up to the desired tension. The large piston is intended to overcome the resistance due to the compression of the air to a moderate degree, while the small encounters the heavy pressure of the final compression.

The features claimed as new are as follows:

1. A new method of taking air, consisting in drawing it from outside through an underground passage, or a large cellar, to cool it before entering the compressor. This is claimed to be of special importance in large plants. At the date of writing (April 1, 1881) the patent for this has been allowed but not issued.

2. Wrought iron guides for the valves, for which patent has been allowed but not issued up to April 1, 1881.

3. An oil-cup for oiling the cylinders, dropping oil through a wick under pressure, with the object of securing regular feed and economy of oil.

4. The pipe-cooler between the compressing cylinders, licensed in part under United States patent 191,868, dated June 12, 1877, and on which there is another United States patent pending (April, 1881).

5. An air-governor, patent dated July 13, 1880, No. 229,821.

6. Lining of air-cylinder, patent allowed but not issued up to April 4, 1881.

7. Attachment for mining locomotive, supplying pumps at very great depths, or drills working in exceptionally hard places and needing heavier pressure than the average of the work. This is patented in the United States, February 1, 1881, No. 237,274. This attachment is fitted to the machine, but only supplied when needed.

The inlet air-cylinder is removed as far as possible from the steam-cylinder and steam-pipes, the arrangement being such that a light partition can separate it entirely from the main engine-room. By this means there is avoided the passing of the air about to enter the compressor directly over this hot surface. In addition to the loss of power in compressing heated air, the rarefaction of the air would reduce the capacity of the compressor. The water-jacket is supplemented by a reservoir between the two cylinders; in this reservoir there are cooling water-pipes. The makers claim that allowing the temperature of air compressed without cooling arrangements to 160 pounds pressure to be raised from 62 degrees to 373 degrees F., the economy of cooling completely would be 21·6 per cent; and that by using two compressing cylinders, with the reservoir between, the temperature of the air from the first cylinder will, under the same circumstances, be 199 degrees, all of which heat above the atmospheric temperature can be taken out by the intermediate cooling reservoir, reducing the amount of power required to 88·1 per cent, leaving only 9·7 per cent to be gained by jacketing the two cylinders.

The stem and valve are forged in one piece by drop-forging.

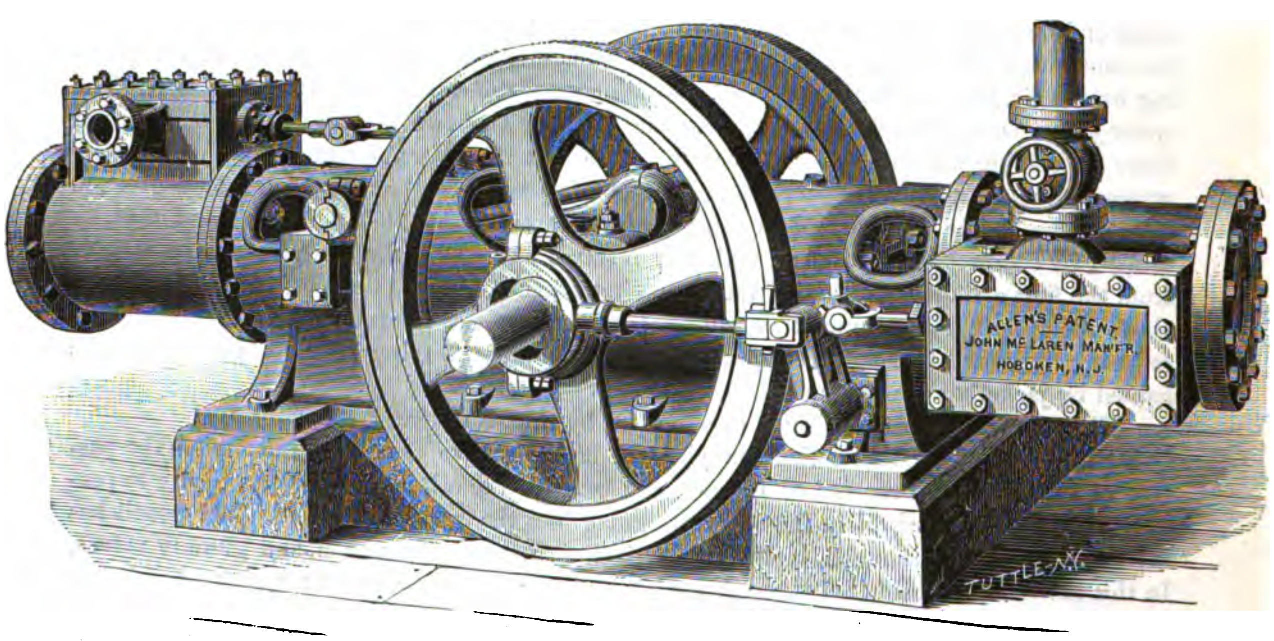
Most oil-cups for lubricating air-cylinders have been so constructed that after the passage of the piston and the fall of the pressure beneath the oil, it has been practically impossible to prevent all the oil in the cup from going into the cylinder at once. The result has been excess of oil consumed, inefficient lubrication, wear of the piston, and gummy valves. In this machine, the oil is fed through a wick, and the changing pressures above and below the body of oil are constantly closed by a special device.

Under E. Hill's patent, July 12, 1881, air-compressors are supplied with cool air for compression by hoods over the inlet-valves, with conduits and air-passages through a chamber connected with the external atmosphere, in which the air is partially cooled before it enters the compressor. The project is to have this cooling chamber (or chambers) on all sides of the foundation of the compressor cylinder; there being a perforated cover or ceiling to this

chamber, forming part of the engine-room floor, and the hoods being removable to allow of inspection of the inlet-valves. In this cooling chamber there may be deflecting partitions to force the air down to the bottom of the pit, and jets of water to cool it.

In order to prevent the useless escape of compressed air, representing the loss of steam in the case of compressors driven by steam; and in order to prevent engines or compressors that are not direct connecting or provided with cranks or fly-wheels from stopping, there has been devised an improvement patented by Hill, July 13, 1880. In this invention there is a conduit between the discharge side of the air-pump or reservoir, and in this connecting passage there is a regulating valve, so that when the air-pressure on the discharge side of the air-pump equals the resistance of this valve, it will open it and let the air, instead of escaping, go into the steam passage, displacing its equivalent of steam, and thus acting as a throttle to the steam in its passage to the working cylinder. By this means the escaping air becomes an automatic governor, permitting the steam-engine to keep its proper velocity without wasting steam, and without much mechanical complication to effect the desired result.

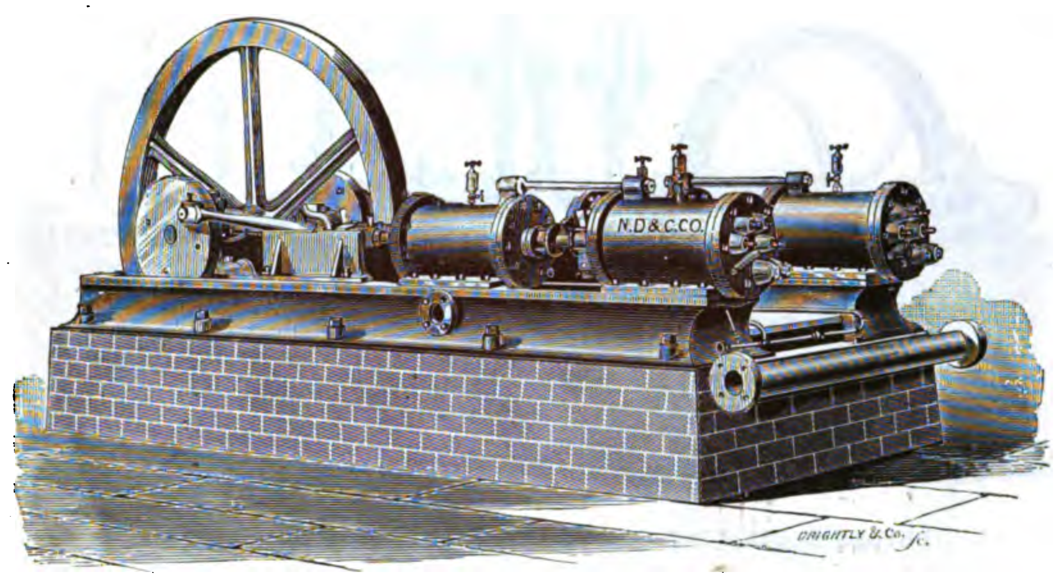
In the United States patent of E. Hill, July 19th, 1881, No. 244,603, it is proposed to utilize heat in the water discharged by the pumps of deep mines, in expanding the air after compression, and to utilize the exhaust air from the last power-cylinder. This is to be done by allowing air from the reservoir under a given pressure to operate a piston for driving the pump, and then permit it to escape as exhaust into a chamber, through which the water from the pump is caused to flow in tubes like a condenser, there, by imparting its heat to the expanded and cold air, causing a further expansion, by which it may be utilized in the larger cylinder to furnish power in driving the pump; and as it is easier to compress air at low temperature, it is proposed to conduct the air from the second cylinder, or the last in the series, to the suction side of the compressor, to be again returned to the reservoir.



THE ALLEN (McLAREN) COMPRESSOR.

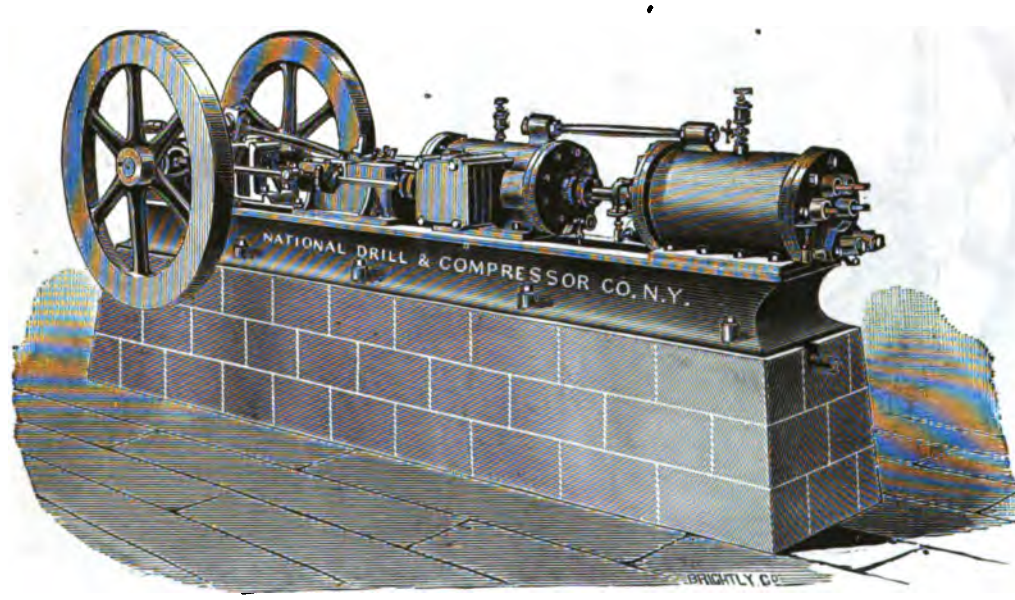
Concerning the Allen Compressor, made by John McLaren, Hoboken, N. J., we can learn nothing save the information conveyed by the circular, that it is a high-speed machine with heavy reciprocating parts, the air-valves being positively-moved slides. [See above.]

In the Ingersoll compressor the air and steam-cylinder cranks are set at an angle of 60 degrees, the steam-cylinder crank behind the air-crank, and suitable counterbalance weights



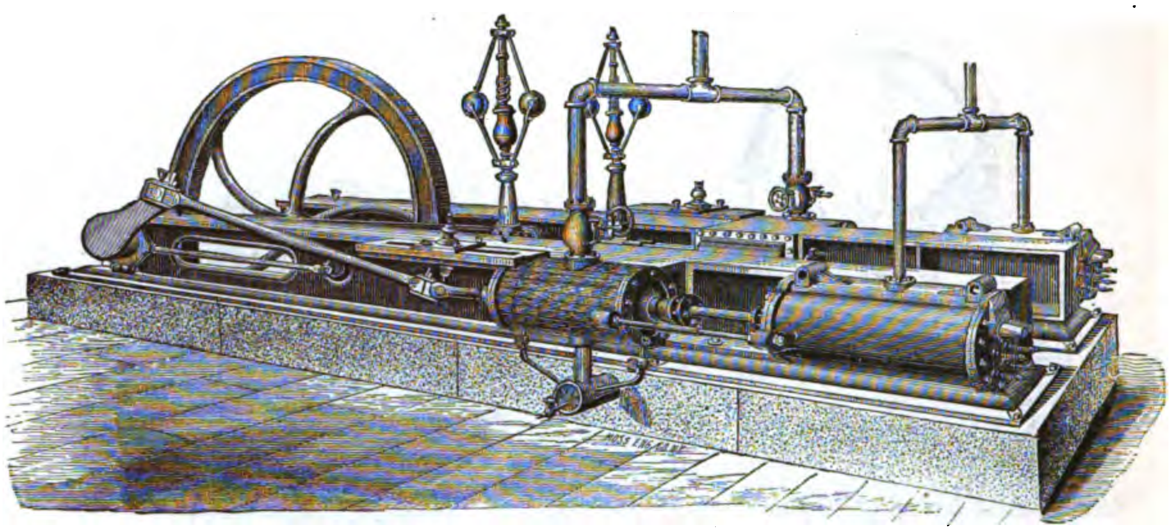
AIR-COMPRESSOR, NATIONAL DRILL AND COMPRESSOR CO.

provided in the fly-wheels. The air admission ports are covered by an ordinary-shaped slide-valve, operated by an eccentric on the main-shaft. These valves place the ports in the

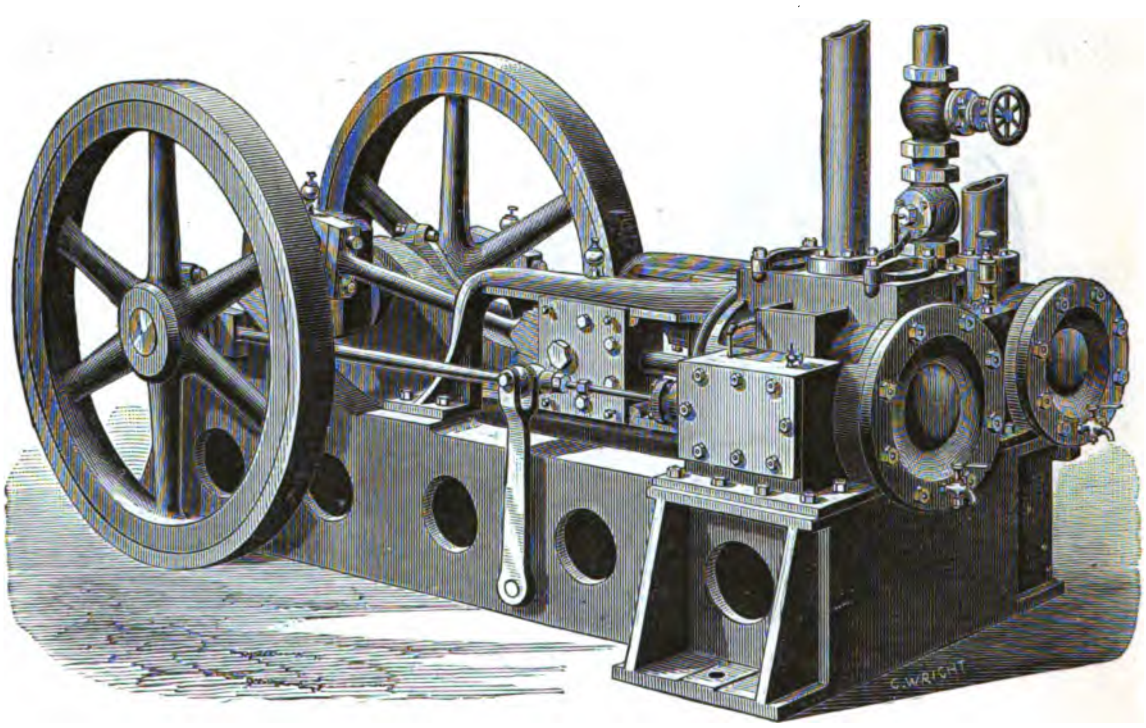


AIR-COMPRESSOR, NATIONAL DRILL AND AIR-COMPRESSOR CO.

end of the air-cylinder in alternate communication with the central port through which air is admitted; this being the port which would ordinarily be the exhaust port in a steam engine.



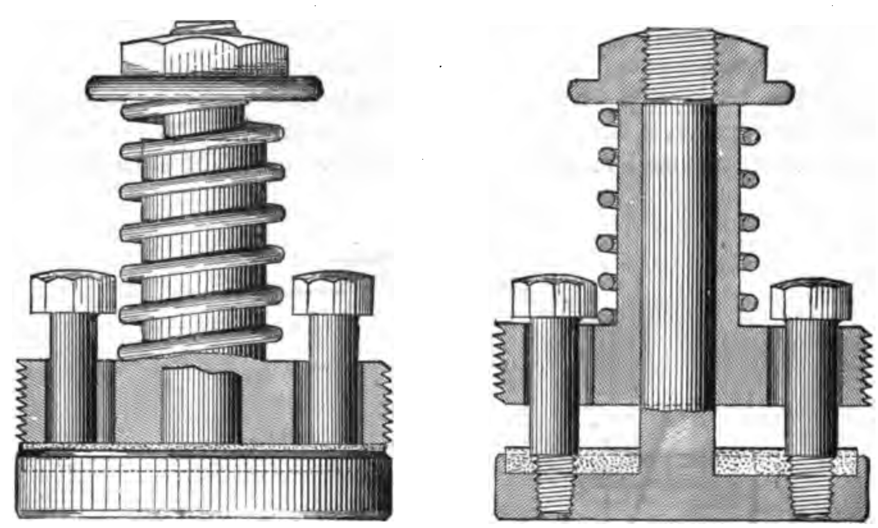
DUPLEX HORIZONTAL COMPRESSOR, INGERSOLL ROCK DRLL CO.



SINGLE AIR-COMPRESSOR, INGERSOLL ROCK DRILL CO.

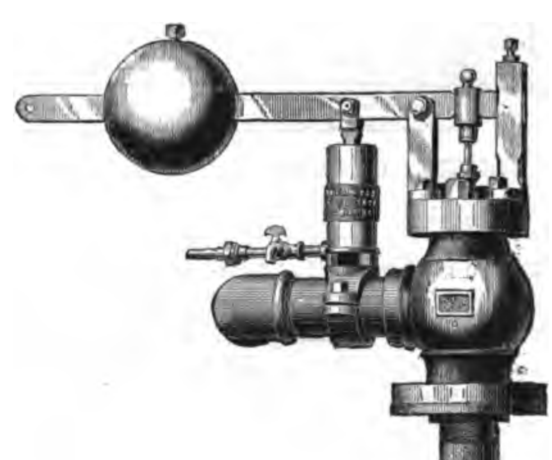
The illustrations on this page show in perspective the "straight rod duplex" and the "side and side" single forms of Ingersoll double-acting Compressors, with steam cylinders. The general principles of these types, and the advantages and disadvantages urged in connection therewith, are fully discussed under the proper heads.

The valve chest is at no time in communication with the ends of the cylinder, being merely a box for the slide valve to work in. The air delivery ports are upon the top of the air cylinder, opening from the ends of the cylinder into the chest, and being closed by poppet valves cushioned by springs, and guided by springs on the valve buckets. The delivery valve



SECTIONS OF VALVES, CLAYTON COMPRESSOR.

chest is connected with the inlet valve chest by a pipe, so that there should always be as much pressure upon the back of the admission slide valve as the air pump has developed in the chest; thus preventing the compressed air from raising the admission slide valve off its seat.



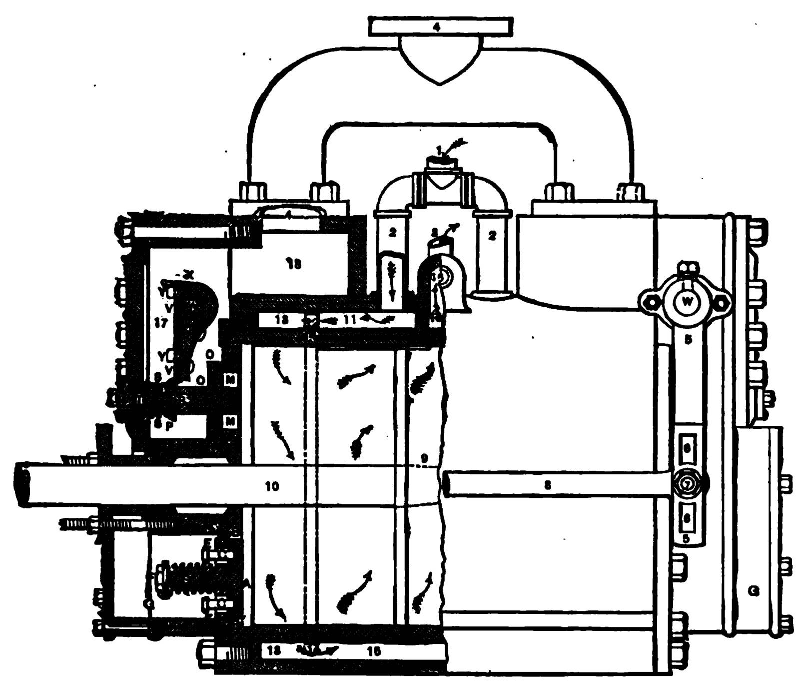
AIR GOVERNOR, CLAYTON COMPRESSOR.

The cooling water is let in through the central admission port of the slide valve, and while some of it remains in the cylinder to fill up the clearance space and the admission port,

the rest is discharged into the bottom of the delivery valve chest, whence it escapes through a pipe.

The present machine, of the vertical type, has cross-heads and guides, and an adjustable cut-off engine, stated to give 20 per cent. increased capacity, and save 25 per cent. of fuel.

In the Clayton long-stroke duplex compressor there is a water jacket completely encircling the ends first and discharging at the top, the objects being to cool the cylinders most where they are most heated, and to insure the jackets always being full. The discharge valves are lifted and tripped by an adjustable drop, letting the air escape as soon as it has reached the working pressure, instead of further compressing it. The cylinder is supplied with water or lubricant at each stroke, and only when working. The yoke is constructed so



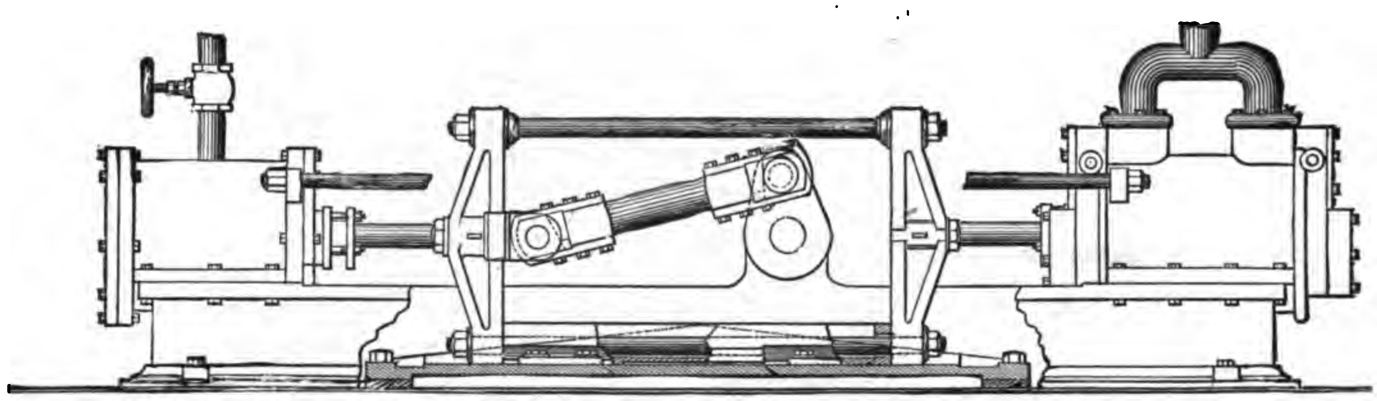
SECTION OF CLAYTON COMPRESSOR.

that the wear can be taken up in the block and in the slides at the same time. There is an air governor (Steele's patent) which keeps the pressure regular by causing throttling of the steam when the air pressure reaches a certain point. The suction valves opening into the air cylinders have safety stems, preventing the valve from falling into the cylinder, or other accidents, if the stem breaks or the nut comes off.

In the Clayton belt-driven compressor the large pulley-wheel is weighted so that the belt lifts the weight to its highest point during the first half of the piston-stroke, while the resistance of the air being compressed is but slight; and then during the second half of the stroke, where the resistance is greatest, the weight helps the belt.

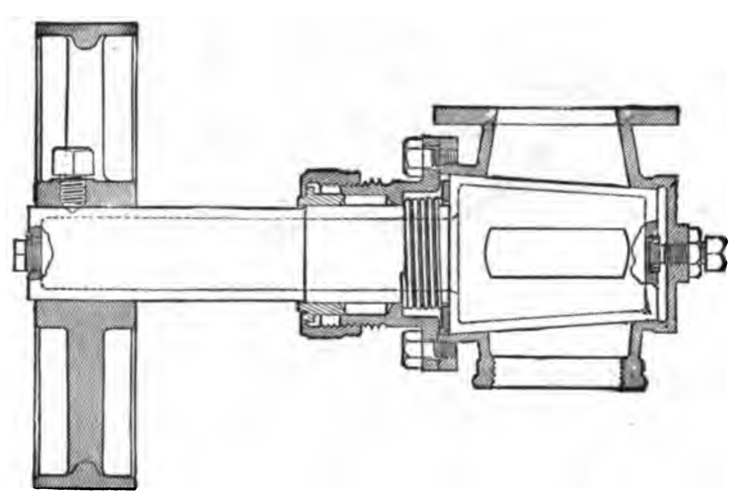
Clayton combats the difficulty of the piston working horizontally by taking up the weight of the yokes, connecting rods, pistons and rods, off the cylinders and stuffing-boxes, and carrying it upon the slipper guides placed under the yokes.

These compressors are built either wet or dry, as desired. Where they are to be run dry without lubrication, the valves are made to suit, and the piston runs very close to the cylinder covers, so as to have no lost space at the end of the stroke. To prevent the cylinder cutting, hemp packing is used.



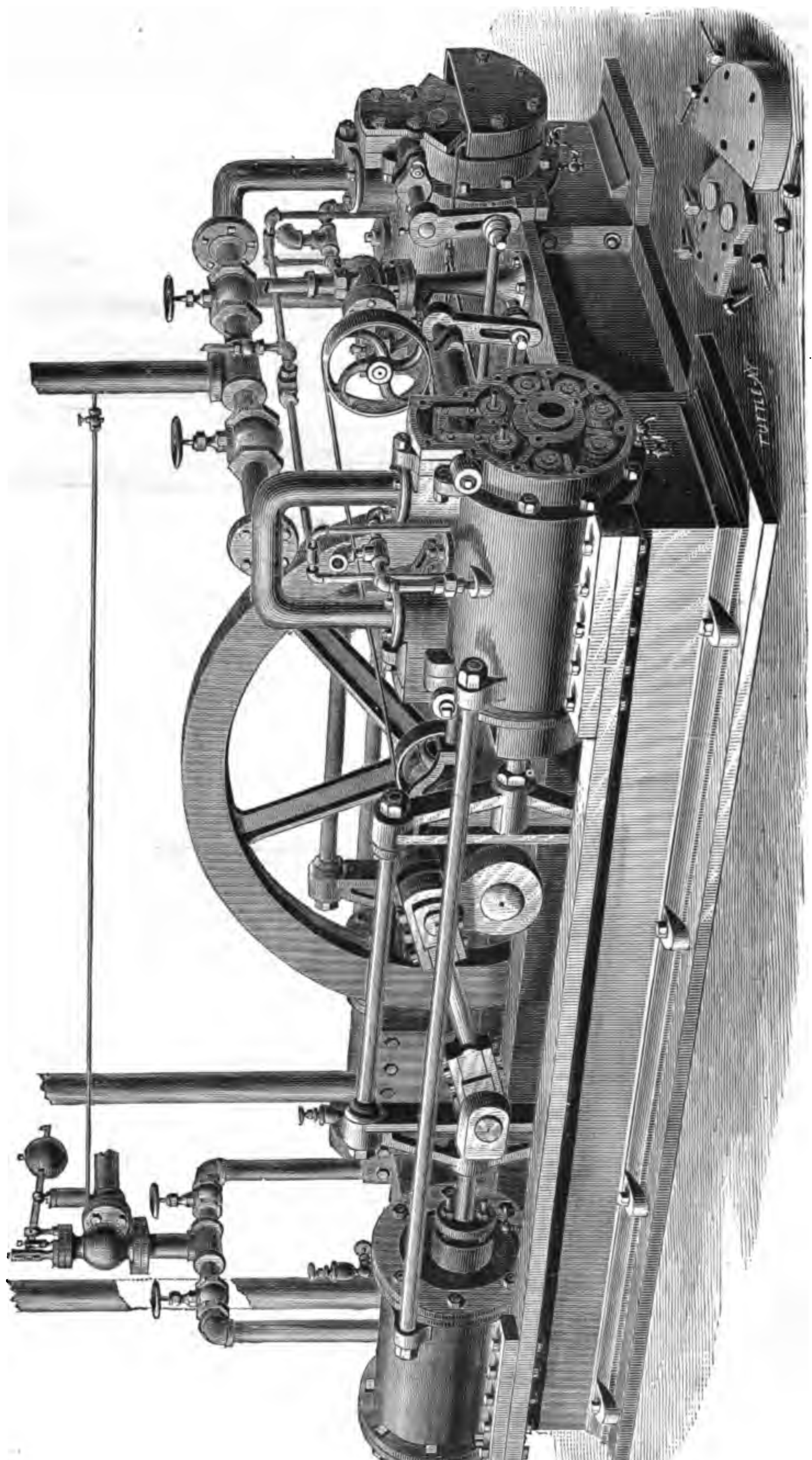
NEW FORM, CLAYTON COMPRESSOR.

In Fish's design for an air-compressor (John Fish, 10 Pine Street, New York), shown on page 167, the air cylinder is bolted to the air-valve chamber, which is cast on a distance piece, which forms the guides for the main cross-head, the other end of the guides being secured centrally to the front end of the steam cylinder. There are two main pillow-blocks,



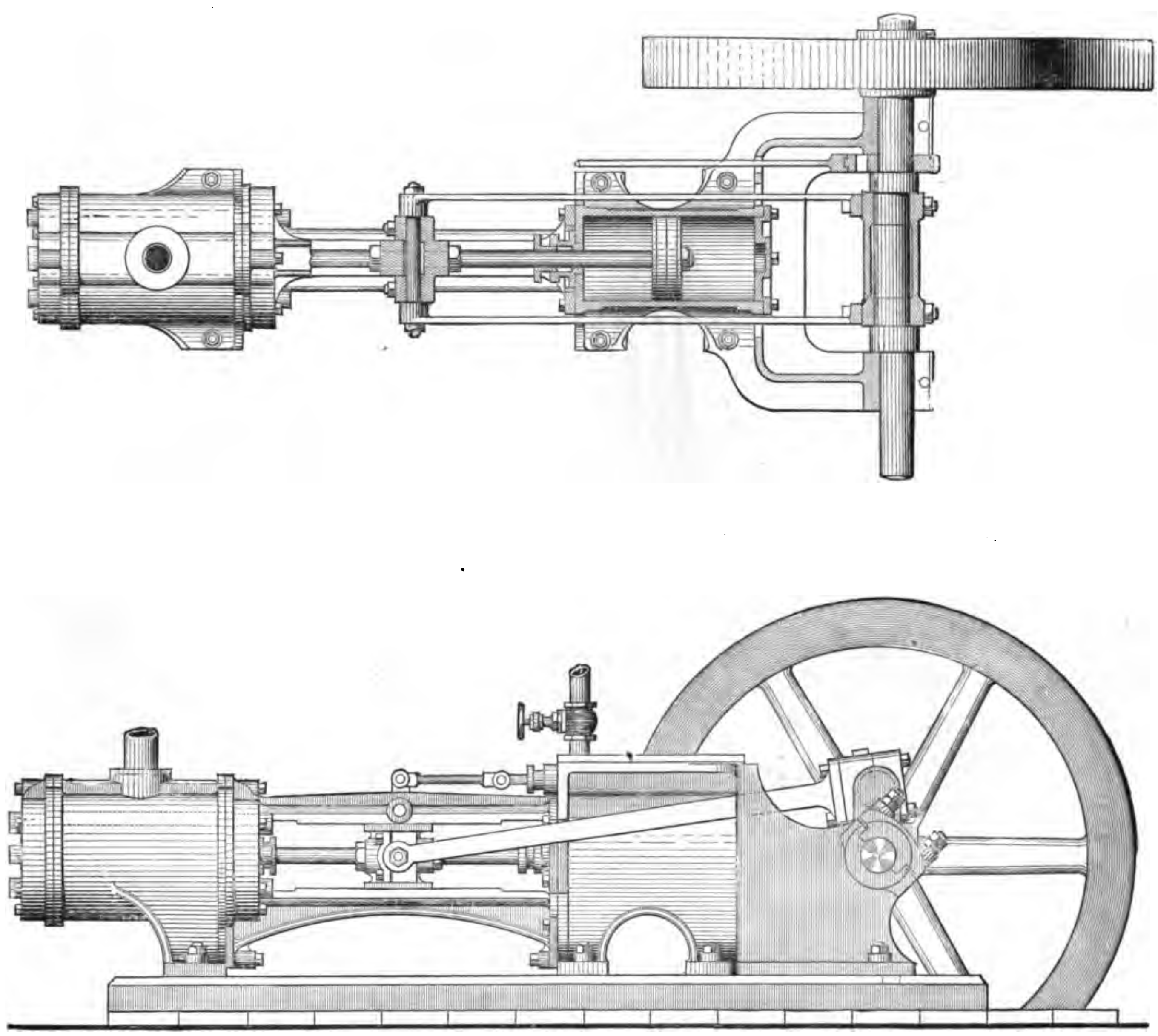
VALVE, CLAYTON COMPRESSOR.

and these are cast on to the rear end of the cylinder. The distance from the centre of the shaft bearing to the end of the cylinder is very short, giving rigidity to the pillow-blocks. There is no bed-plate; all the parts are separate, as air cylinder, distance guide piece, steam cylinder, pillow-block, shaft, and fly wheel. The power is transmitted from the cross-head



CLAYTON LONG-STROKE DUPLEX COMPRESSOR.

through the connecting-rod to the crank-shaft in a peculiar manner. The connecting-rod has two bars working outside of the steam cylinder, and rigidly connected at one end to a single pin working in the cross-head; the opposite end connecting with a single journal box work-

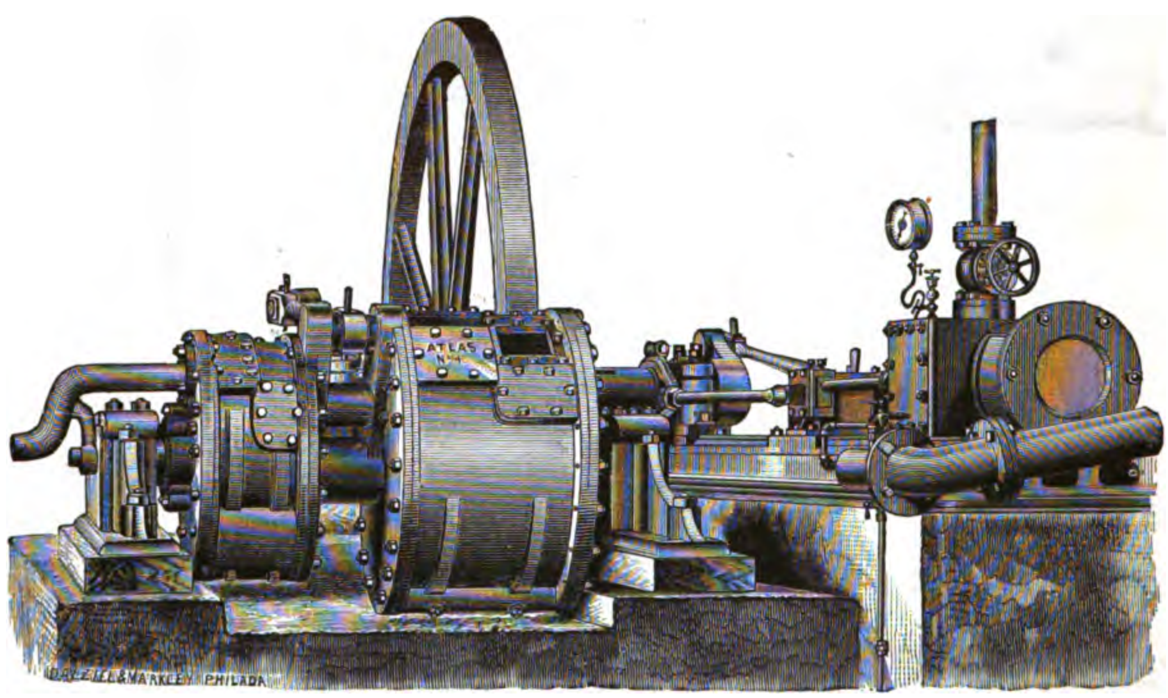


FISH'S DESIGN FOR AIR-COMPRESSOR.

ing upon the crank pin. Thus the connecting-rod acts like a single rod, keeping square with its bearings when the wear is taken up at either end. The crank-cheeks are separated far enough apart to allow access to the steam piston, which can be removed with its load from

the cylinder, without disturbing the crank-shaft. The steam valve shown is of the ordinary *D* slide type. Cooling is by water jacket.

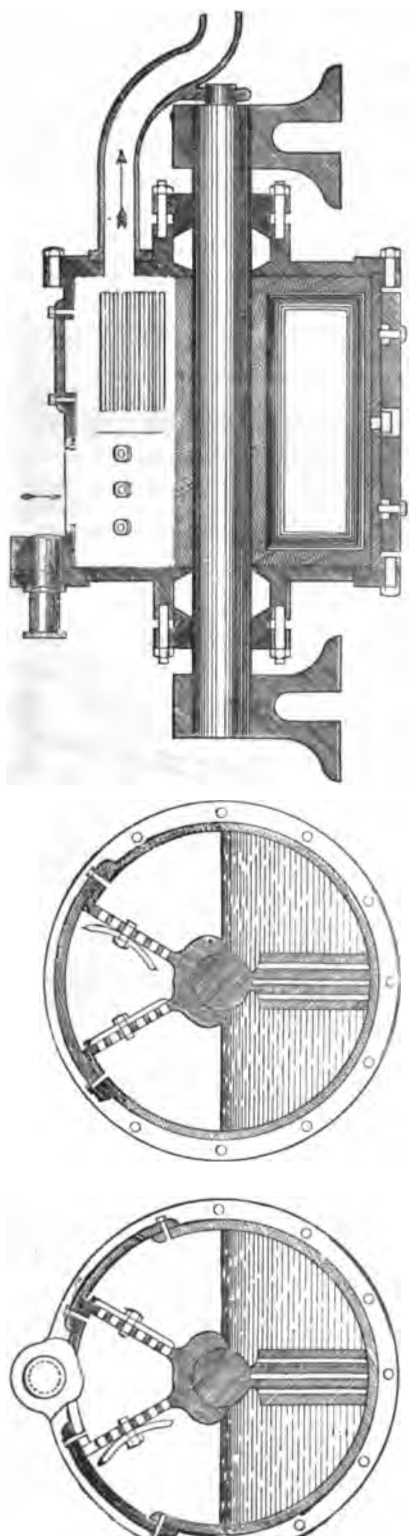
In the latest form of the Johnson Compressor, recently shown at the Franklin Institute and here illustrated, there is a cylinder of any diameter and of proportional length, having covers bolted on at both ends, in the centre of which there are stuffing-boxes. Through these there is a shaft having on its lower side a square wing entering downward and filling the space between the shaft and the lower side of the cylinder, and extending lengthwise to both ends of the cylinder covers, so as to divide the lower half of the cylinder into two compartments, leaving sufficient space between the wing and the cylinder-covers to permit a free motion of the cylinder when this is oscillated upon its shaft. At the upper part of the cylinder there are two valve chambers, end to end, the first for the inlet and the second for



JOHNSON'S COMPOUND OSCILLATING WET COMPRESSOR.

the outlet of air. The sides of this cylinder cross the chamber lengthwise, and are about 60 degrees apart; the upper or larger radius being fastened air-tight to the upper half of the cylinder, and the ends of the chambers fastened to the cylinder-covers, the lower or smaller part resting upon the upper part of the central shaft, forming a cylindrical bearing, which, with the cylinder and the covers, may oscillate upon the shaft, the shaft itself and the lower portion being stationary. The end of the shaft, passing through the stuffing-boxes of the covers, is keyed in proper pedestals. The cylinder-covers and valve-chambers are in one piece, and can oscillate through an arc of about 120 degrees. If there be water in the lower half, there will be formed two air-tight compartments, the water acting as a packing and as a lubricant, and absorbing the heat of compression. The cylinder slides past the water, which

is not itself put in motion. At each oscillation the central upper valve comes in contact with the surface of the water, which absorbs at every stroke nearly all the heat absorbed by the upper part of the cylinder.



JOHNSON'S COMPRESSOR.

Lengthwise and Vertical Sections.

Transverse Vertical Sections.

The Hydraulic Works of Philadelphia make a horizontal compressor from the designs of Mr. B. Frank Teal. In this machine the steam and air cylinders are side by side. The steam cylinder is of less diameter than the air cylinder, being 18 inches bore and the air cylinder 24, the stroke of each being 24 inches. The steam pressure used is about 70 pounds, to give 40 pounds of air. The steam is worked expansively. The cranks are set quartering. The cooling is effected by means of spray, but if ordered, a jacket will be supplied in addition. The discharge valve is automatic; the valve is of the same kind as that used by Griffith & Wedge, being a piston valve with an incline of 60 degrees; is of brass upon an iron seat. The piston has a half ring of lignum vitæ in its lower circumference, to lessen friction.

Flower Compressor (Scientific American Supplement, October 20, 1877, page 1491). The compressing engines at the Powell Duffryn Collieries, South Wales, have steam cylinders coupled together at right angles, the steam cylinder being 34 inches, and the air 40 inches diameter, the stroke being 6 feet. The steam at 70 pounds per square inch is cut off at $\frac{1}{4}$ stroke, and the air compressed to 40 pounds per square inch. There are in each cylinder-cover of the air cylinders three cast iron inlet valves with leather flaps. In each cover are two brass outlet valves with mitre faces, $1\frac{1}{4}$ inches long, inclined 30 degrees to the valve spindle. The air cylinder is set in the water trough. There is no water spray. The engines at 20 revolutions (or at a piston speed of 240 feet per minute) indicate 482 horse-power.

	Square Inches.	Cubic Feet.
Area of air cylinder	1256	....
Contents of stroke................	....	104.6
Contents of stroke per minute......	....	4185
Contents at 67 per cent. of the stroke	....	2804
Compressed to pounds per square inch	....	934
Area of three inlet valves	64·8	....
Area of two outlet valves..........	43·2	....

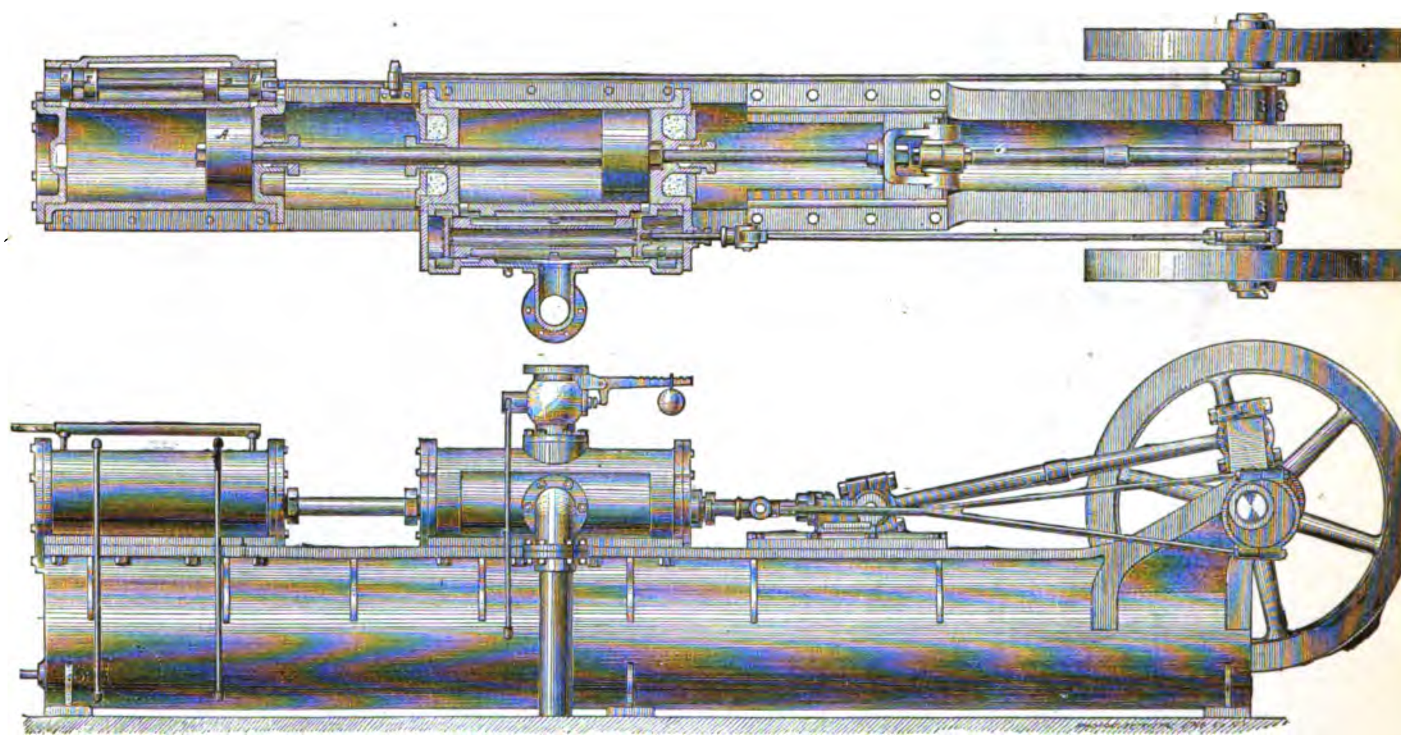
THE DYNAMIC AIR-COMPRESSOR.

The Dynamic Air-Compressor, built by the Graydon & Denton Mfg. Co., of Jersey City, New Jersey, has only just been brought into notice.

"It is designed to secure the advantages attending the use of slide valves to govern the inlet and outlet of the air; namely, the least possible leakage, and slip, and the attainment of high speeds, thereby reducing first cost; while the advantages possessed by poppet valves, such as small clearance and perfect balance, are claimed to be fully equaled in the type of slide valve employed." The bed is cylindrical and serves as a receiver, or tank, in which the pressure is maintained about uniform by a regulating valve in the steam pipe.

Provision is made for the injection of water into the cylinder under the pressure of air in the receiver, and for an additional supply from a small tank to the induction ports. The water, after passing through the cylinder into the receiver, is automatically returned to the tank, when more than is requisite for injection has accumulated.

This compressor is double acting, and may be built to be driven by steam, as shown in cut, or by belts or gearing, or to couple direct to a water-wheel shaft running at high speed.



When more air is required than can be economically supplied by a single cylinder, the manufacturers of this compressor recommend two independent compressors of smaller size, rather than a duplex machine. The steam valve is of the plain Allen type, in piston form, the seat being a brass sleeve easily renewable. The action of the air valve, covered by patent of Mark S. Manning, Jr., is as follows: As the piston *A* moves in the direction of the arrow, the valve *B* begins to open the port and air enters through the open end of the valve chest. At the other end of the cylinder the air is compressed until its port is opened by the valve *C*, which being joined to *B* by the rod *D* is moved with it by the eccentric.

When the pressure in the cylinder exceeds that in the receiver, the auxiliary valve *E* sliding along *D* opens the eduction valve, and the air is forced into the receiver.

The reverse operation occurs on the return stroke.

A. Normandy Stillwell & Co., London, England, Custom-House Station, Victoria Docks.—This machine is illustrated in the "Engineer," May 16, 1879, page 352. There are two vertical cylinders placed side by side, and worked by two eccentrics on a shaft,

so that one is up while the other is down. The cylinders stand in a tank of water, and there is a groove turned in the plungers, which at every stroke becomes full of water which is carried down by the plungers to lubricate them and make them air-tight. The air enters and escapes from the cylinders by a cock, the plug of which rotates continuously, being worked by a rod and bevel wheels, so geared that the cock makes one revolution for every two turns of the shaft, hence making one-quarter revolution for each complete stroke of the plungers. This is made under E. Edwards' patent.

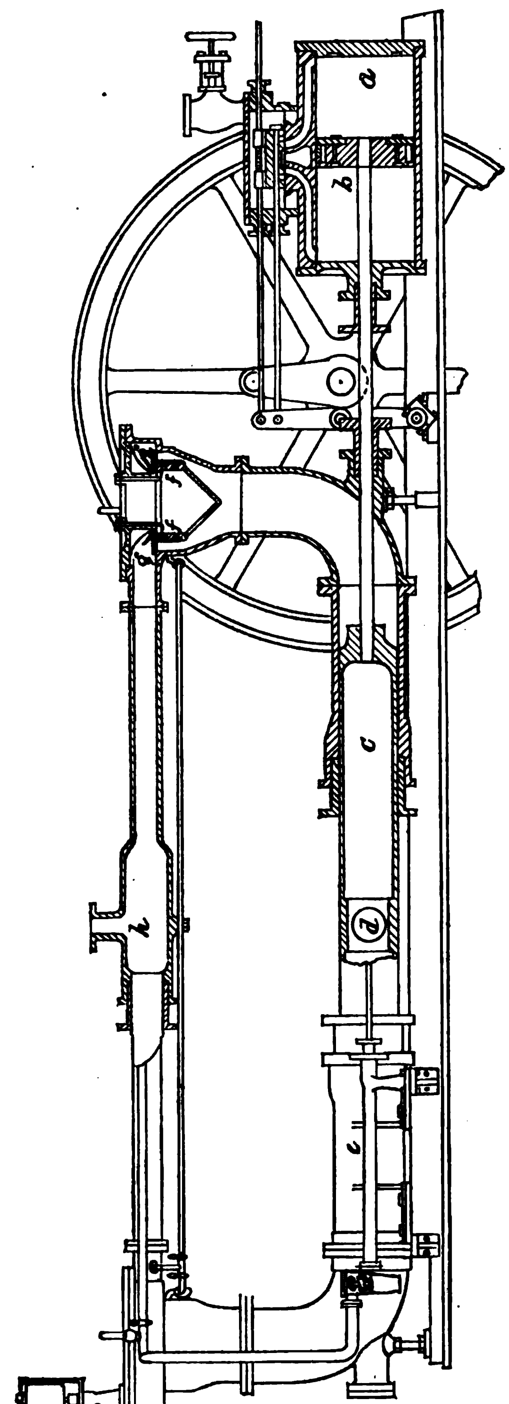
At the Festiniog Tunnel the compressors are mounted on the receiver. The air cylinders are surrounded with water and are double acting, 16 by 30 inches. At 60 revolutions per minute there is enough air compressed to run two drills with 4-inch cylinders.

At Altenberg the Prussian engineers obtained 96 per cent. of the volume due to the stroke of a wet compressor. At Saint Gothard the Colladon Compressor compressed 70 per cent. of the volume of the stroke. With wet pumps the heating of the cylinder reaches 77 degrees to 80 degrees F.; while with dry, at high velocities, 175 degrees F.

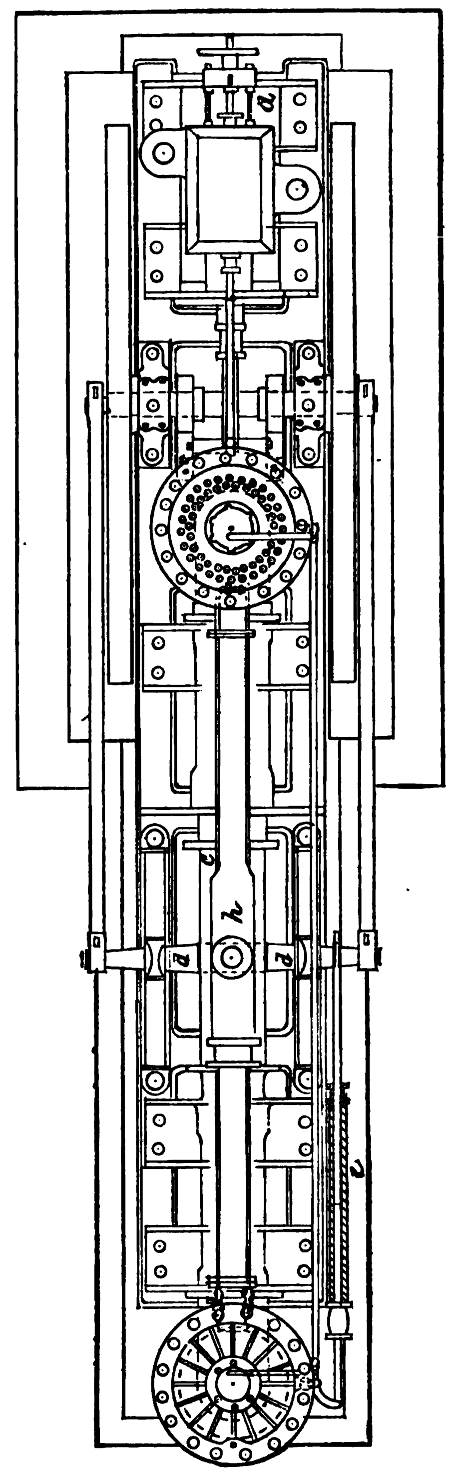
Excellent illustrations and descriptions of the ones used at the Mt. Cenis Tunnel will be found in Mr. Sopwith's papers on Mt. Cenis, "Transactions Inst. Civil Engineers," London, vol. xxiii., p. 258, and vol. xxxvi., p. 1. In this paper will be found illustrations of Sommeiller's early hydraulic ram, his "*Compresseur à coup de bélier.*" Illustrations and notes on the same will also be found in Zwick's "*Neuere Tunnelbauten,*" p. 58; and in Schoen, "*Der Tunnelbau*" (ed. 1874); also in "Engineering," vol. xii., pp. 283, 367, (1871). These rams were devised by Sommeiller, and were subsequently superseded at Mt. Cenis by the early forms of the wet compressors of the present day. They are now of historical rather than practical interest, so that only an outline of their principle will be given here for those who are not familiar with them. The following description is from the report of Mr. Charles S. Storrow, on "European Tunnels," to the Massachusetts State Commission on Hoosac Tunnel, February 28th, 1863.

We will consider, first, the receivers to hold the compressed air, and, second, the machinery to compress the air and supply the receivers.

First, the receivers were iron cylinders, with spherical ends, made of boiler-plate. There were ten of these in 1862 at Bardonnèche, set up in two groups, of five each, all communicating with each other so as to make virtually but one, the aggregate capacity of the whole being some 170 cubic metres, or 6000 cubic feet. They were erected in a large building standing about half a mile from the mouth of the tunnel. On the hillside, at the height of about 50 metres, or 164 feet, above the receivers, was a reservoir of water, with a surface of over 3000 square feet, supplied by pipes laid from a small but permanent stream. By means of a constant influx and ample means for overflow, the surface of this basin was kept permanently at the same level. From this, two iron pipes, which are called the manometric pipes, each 0·30 metre, or about one foot in diameter, were brought down to the two groups of receivers, with each of which one of them freely communicated. The air inclosed in the receivers, which at first was in its ordinary atmospheric condition, was therefore constantly pressed by the weight of a column of water, 164 feet in height, acting directly against it, which was equivalent to about five effective atmospheres, and would, of course, be condensed until its pressure exactly counterbalanced that of the column. If a portion of the air in the receivers were now drawn out for use, the water descended by the pipes to supply its place and maintained what remained in them at its original pressure. If air, on the other hand, were forced into the receivers, it expelled an equivalent amount of water, which was thus thrown back into the upper basin, and the pressure remained precisely as before. The water let down in the first case was instantly supplied by the influx into the basin, and that thrown up in the second was instantly discharged at the overflow, so that the surface of the basin remained uniform, the column of water pressing against the air in the receivers being



Elevation.
FIG. 77(a).



Plan.
FIG. 77(b).

HUMBOLDT AIR-COMPRESSOR.

(a), Steam-cylinder. (b), Piston. (c), Plunger. (d), Cross-head. (e), Force-pump. (f), Inlet-valves. (g), Outlet-valves. (h), Delivery-pipe. Scale, $\frac{1}{40}$.

constantly of the same height, and the air constantly remaining at the same pressure—*i. e.*, at a pressure due to 164 feet of water. Glass tubes connected with the receivers showed on the outside the height at which the water stood on the inside, so that the supply of air furnished to them might be increased or diminished, according as a greater or less quantity was drawn out for use upon the works.

Second, means for compressing air to supply the receivers.

At Bardonnèche this was done by compressors worked by water-power. The water came from a well-built stone dam erected across a small stream, from which it was conveyed a distance of nearly two miles to the compressors by a canal lined with masonry, about four feet wide and three and a half deep, in which it stood at the depth of 24 to 27 inches. This canal had a constant but not a uniform slope, and the velocity attained was very great. The water was opaque, turbid, and, like all the waters of the region, discolored by the calcareous rocks and earths through which it passed. In order to clear it from sediment and other impurities, it was first admitted into a large basin with a surface of 16,000 square feet and a depth of 5 feet, where it lost of course its velocity, deposited what it had in suspension, and passed out again by a grated opening, the bottom of which was 27 inches below the surface. From there it continued again its course, by the canal, to a second and smaller basin near the works. From there, again, it passed through a double set of wire gratings into a third basin, standing at the height of 45 metres, or 147 feet above the receivers. All these precautions were necessary to secure water free from impurities or foreign substances, which might be very injurious to the stop-cocks or valves through which it afterward had to pass. From this third basin, the water was let down by two iron pipes, each 0·50 metre, or 20 inches in diameter, to a reservoir built in masonry, forming the upper or second story of a building erected for the purpose, where it stood at the level of 25 metres, or 82 feet above the receivers, and close to the building which contained them; and it was from this last reservoir that it was let directly on to the compressors. The object of the whole work thus far, therefore, was simply to supply water to a reservoir 82 feet in height above the point where the water was to be used. The long distance from which it was brought, the deposit-basins on the line, the height of 147 feet at which the third basin was situated, all these were peculiarities indicated or required by local necessities, resulting from the rough topography of the region, or the peculiar character of its water.

Between this reservoir and the air-receivers placed in the building just below it, were the ten compressors. These were ten iron pipes, all precisely alike, in free communication with the water in the reservoir, and descending from it at an angle of about 45°. They rested upon solid masonry built upon the side-hill, and entered the building in which the ten receivers were erected. Each pipe, as it entered the building, was turned vertically downward, as shown in Fig. 78, and, after a short horizontal course, rose again vertically, and was then placed in communication with the upper part of the receiver, to which it corresponded. In the vertical branch near the receiver, at A, was a valve opening inward to the receiver, and which, though pressed on one side by the water held in the compressor-pipe, tending to open it, was pressed on the other by the confined air, which had the force of a column of water twice as high held in the manometric pipe, and therefore kept it tightly closed. Directly under the valve A were four small valves *v* in the side of the pipe, by which outward air might be admitted; but opening inward to the pipe, they were, of course, kept closed by the pressure of the water within it. On the horizontal branch was an escape-cock B, by opening which the water might be let out of the pipe. On the other side, at C, was a cock by which the communication with the reservoir might be shut off at pleasure.

We have thus an iron pipe full of water, descending from the reservoir, with which it freely communicates, and holding water with a pressure of 82 feet against one side of a valve

A, opening into the receivers, which is held down on the other side by air exerting a pressure equivalent to 164 feet. We now close the cock C, and thus shut off the water in its descent from the reservoir. We open the escape-cock B, and the water below the valve A, in the branch next to the receivers, will descend and escape until it reaches the level of the cock B, which may then be closed, and the air will enter by the four small valves v and

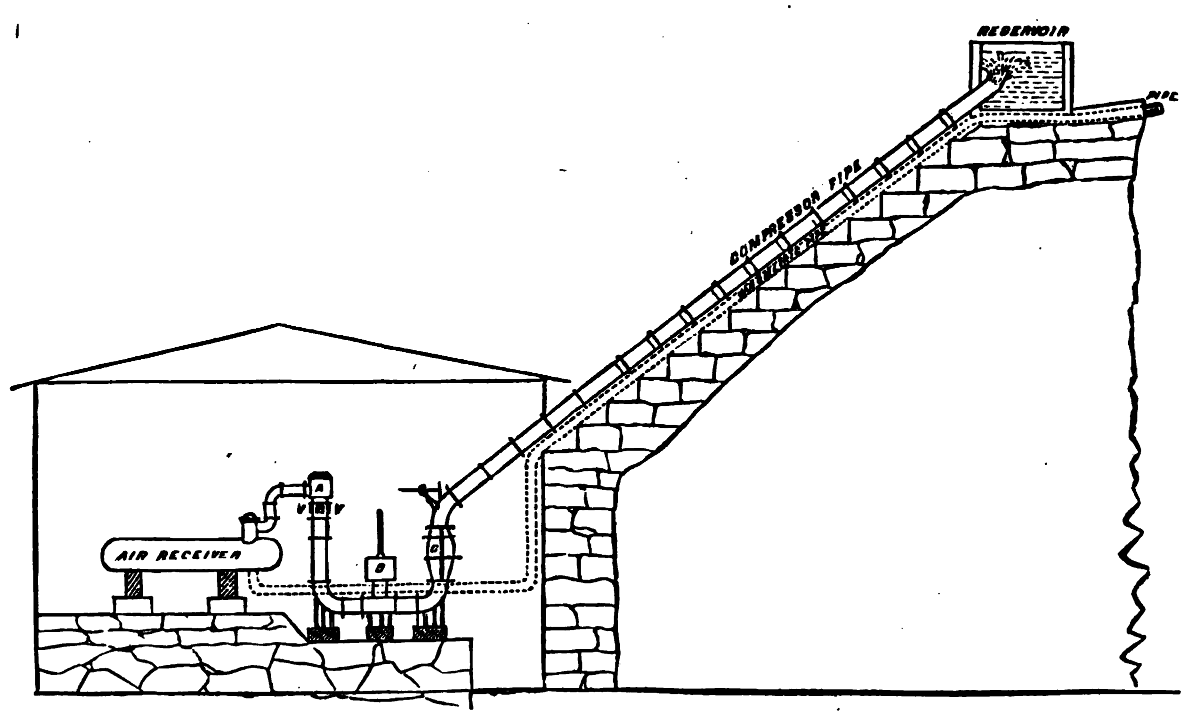


FIG. 78.

SOMMEILLER'S RAM FOR COMPRESSING AIR AT MT. CENIS TUNNEL.

supply its place. The pipe will then contain a small column of ordinary atmospheric air in its vertical branch directly under the valve A, and the rest of the pipe remain filled with water. If we now suddenly open the stop-cock C, which holds back the water of the reservoir, that water exerts its pressure, instantly acquires motion, and drives the small column of air which the pipe contains violently against the valve A, by its *shock* exerts against it a force much greater than that due simply to its pressure, compresses it sufficiently to throw open the valve, and injects it into the receiver. The reservoir is now again shut off by closing the cock C, the escape-cock is opened, and another column or charge of air introduced into the pipe by the valves v; the escape-cock is shut, the reservoir is again let on, the water-ram again produces its effect, a second charge is injected into the receiver, and thus the process is repeated.

The foregoing description, imperfect as it is and must be without drawings in detail, may yet serve to give a general idea of these compressors. Their action was intermittent like that of a water-ram, exerting for an instant a pressure fully twice as great as that due to the column of water which they contained, and at each stroke injecting a certain volume of compressed air into the receivers. The precise height of the valve A above the escape-cock B, which of course gives the height of the column of air which, at every blow, is to be compressed and injected into the receivers, was accurately determined by Mr. Sommeiller, by calculation and by experiment, so that exactly the whole of it should be driven through the valve

by the shock of the water. The form of the stop-cock C was also contrived in such a manner that, when opened, it should form the least possible obstacle to the sudden pressure and motion of the column above it; and by an ingenious combination of cams and levers, the cocks B and C were opened and shut precisely at the proper instants. The power to move them for the ten compressors was furnished by two small engines erected in the building, run by compressed air. They operated with perfect regularity, and this was very necessary, otherwise the pipes themselves would be exposed to the shock which, transmitted to the column of air to be injected, spent its violence in compressing it.

As to the compressor system of St. Gothard,* there is an excellent, clear set of illustrations in Mr. Christopher Klar's paper on "Die Arbeiten und Maschinenanlagen am St. Gotthard Tunnel" ("Zeitschrift des Oesterr. Ing. und Architekten-Vereins," vol. xxvii., 1875, p. 101).

They will, however, be found described in fuller detail, with illustrations, etc., in the "*Rapports Trimestriels du conseil fédéral Suisse sur la ligne du St. Gothard.*" Also see illustrated pamphlets on "Description of Air-Compressors made by B. Roy & Co., Vevay, Switzerland," H. W. Pendred, C. E., 23 Leadenhall St., London, E. C. Also "*Die Maschinellen Arbeiten zur Durchbohrung des Gotthardtunnels*," by Prof. D. Colladon, Zürich, 1876.

The Humboldt and Cockerill compressors shown above are fair types of the best European makes of the present day. As will be seen, they belong to the water type, and, indeed, the general leaning in Europe seems to be toward compressors of this kind.† A good description, with cuts, of Sautter, Lemonnier & Co.'s compressors (Paris) will be found in the "Practical Magazine," for January, 1876, pp. 10 and 12. They are built on the Colladon plan.

There are no English compressors as yet sold, (that is to say, compressors of purely English invention) that can compare with either the Continental or the American makes. Sturgeon's is probably the best, and a description of his compressor, with sectional drawings, will be found in "Iron," vol. vii., p. 708, June, 1876. Also see "*Die moderne Sprengteknik mit Bohr- und Schräm-Maschinen*," by Julius Mahler, Wien, 1876, p. 18.

A series of interesting cards, intended to exhibit the effect of the various appliances adopted by Mr. Clayton in his compressors, has been published in the *Iron Age*. The accompanying illustrations show indicator cards taken from a Clayton compressor under different conditions, the object being to demonstrate the efficiency of some of the appliances of that machine. Aside from the value which these cards possess as indicating the work of this special compressor, they are of interest as affording an excellent means of studying the bearing of disturbing influences upon the work of the machine.

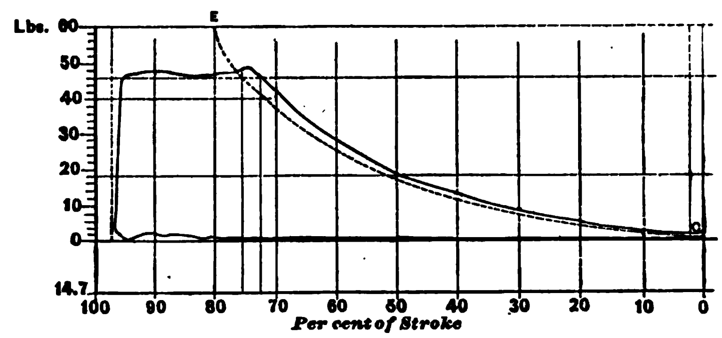
The more extended use of indicator diagrams to test the efficiency of air-compressing machinery, and detect any faults of construction and mounting, is an evidence of progress.

Card No. 1 was taken from the air cylinder of a compressor running at the rate of 65 revolutions per minute, and delivering air into a receiver the safety valve of which was set at 45 pounds. The diagram is almost perfect. The line almost follows the adiabatic curve during compression, proving the increase of temperature of the air to have been slight, a

* An article on B. Roy & Co.'s compressors will be found in "The Engineer" of April 7th, 1876, and "Engineering," vol. xxi., p. 273, April 7th, 1876.

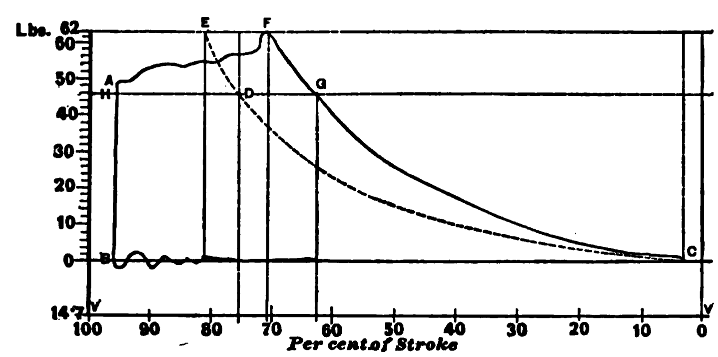
† Prof. A. Riedler, Polytech. Sc., Vienna, Austria, concludes, from his investigations, that the dry compressor works with most economy in regard to power, and the wet compressor with most economy with regard to repairs.

fact due to careful jacketing. There was only a slight excess of pressure in the cylinder over that of the receiver before the delivery valves were opened by the "tripping device."



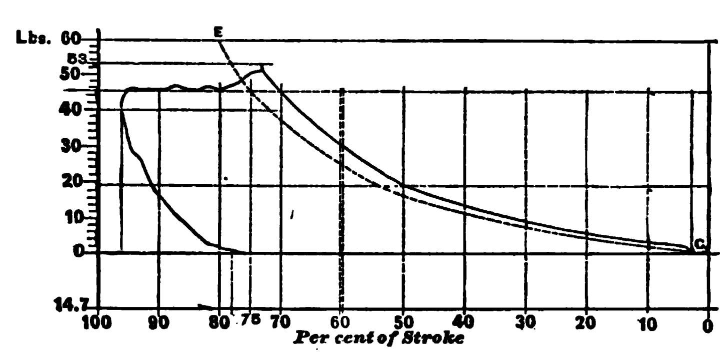
No. 1.—Speed, 65 Revolutions per minute. Scale, 40. Receiver Pressure, 46 lbs.

Without the latter, and without water flowing through the water-jacket, a diagram like that of No. 2 was produced, the speed being 53 revolutions per minute, and the receiver pressure 45 pounds. The air in the cylinder expanded rapidly, as shown by the increase of



No. 2.—Speed, 53 Revolutions per minute. Scale, 40. Receiver Pressure, 45 lbs.

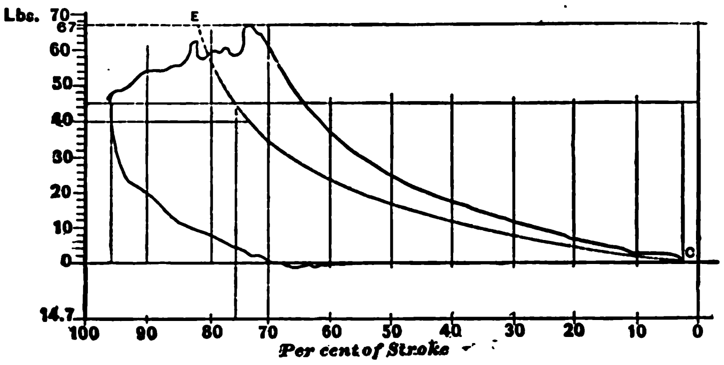
pressure, and as indicated by the relation of the pressure line and the adiabatic curve. Before the discharge valves would open automatically, the pressure in the cylinder had risen as high as 62 pounds, or 17 pounds above receiver pressure.



No. 3.—Speed, 53 Revolutions per minute. Scale, 40. Receiver Pressure, 45 lbs.

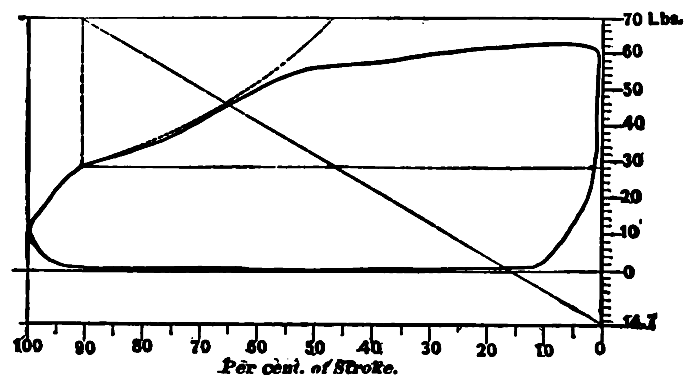
Card No. 3 shows a diagram taken when the suction-valves were lifted automatically, and no water was introduced into the cylinder, as it is generally done for the purpose of lubrication and of displacing all the air in the clearance spaces. The most striking defect caused thereby is the expansion, in the back stroke, of air compressed.

The last card, No. 4, was taken from the cylinder without water in the jacket or in the cylinder, and without the "tripping device" for lifting the discharge valves. The result is a



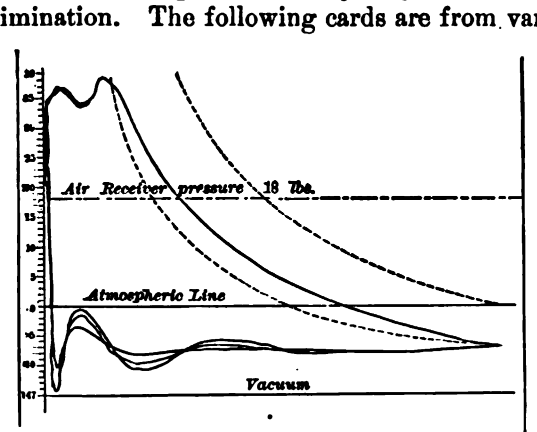
No. 4.—Speed, 53 Revolutions per minute. Scale, 40. Receiver Pressure, 45 lbs.

rapid increase of pressure, due to the lack of any provisions for cooling the air, and running far beyond the receiver pressure, causing a waste of power by re-expansion of air already compressed.

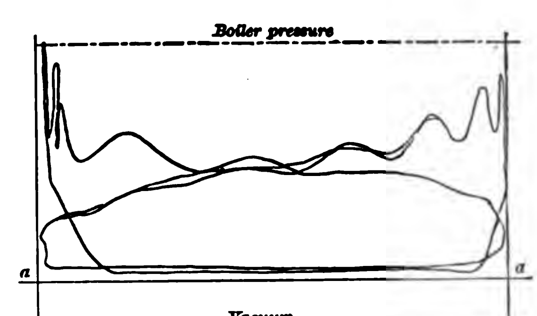


STEAM DIAGRAM FROM CLAYTON COMPRESSOR.

Frequent study of the operation of compressors through the agency of indicator cards, will do much to point out temporary or inherent defects, and be the first step toward their elimination. The following cards are from various machines:



A.—Air Card.



B.—Steam Card.

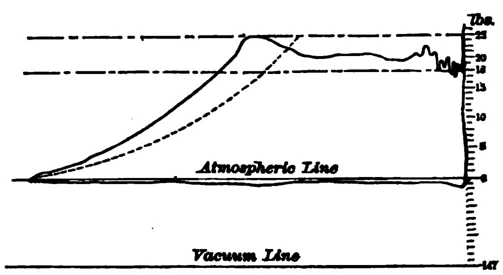
Air cylinder, 12″ x 12″.
Steam cylinder, 10 x 12″.
Area Card (total, 5° 29″ Boiler).
Area above atmosph. line, 4° 2″.
Temperature of room, 53° F.
Revolutions per minute, 200.
Air pressure, 18 pounds.
Steam pressure, 75 pounds.
Area below atmosph. line, 1° 09″.
Temp. of metal of cylinder, 149° F.

Air cylinder, 12″ x 12″.
Steam cylinder, 10″ x 12″.
Scale, 30″.
Revolutions per minute, 200.
Air pressure, 18 pounds.
Boiler pressure, 75 pounds.

The indicator card *A* was produced by the cylinder giving the steam card *B*.

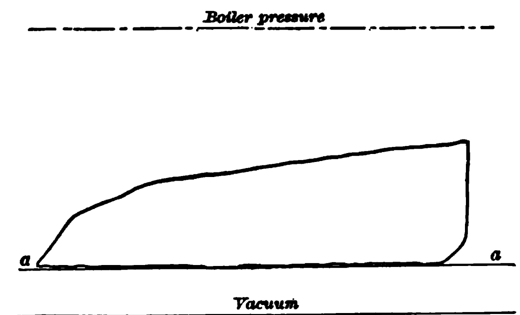
Card *C* is from the same machine which produced Card *A*, but taken at the slowest

speed at which the machine would pass over the centres—32 revolutions per minute. In this card the same criticism might be advanced as upon card A, but of course is not so



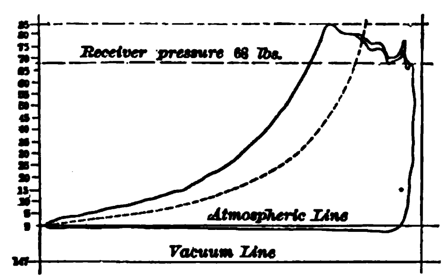
C.—Air Card.

Steam Cylinder, 10 x 12". Revolutions per minute, 32.
Air cylinder, 12 x 2". Receiver pressure, 18 pounds.
Temp. of air in room, 51° F. Boiler pressure, 75 pounds. Scale 16".



D.—Steam Card.

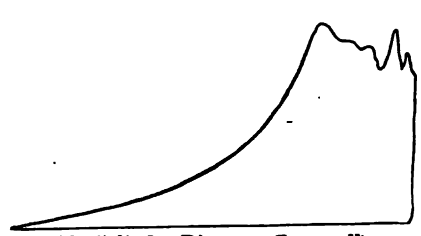
Air cylinder, 12' x 12. Revolutions per minute, 32.
Steam cylinder, 10 x 12. Air pressure, 18 pounds.
Scale, 30". Steam pressure, 75 pounds.



E.—Air Card.

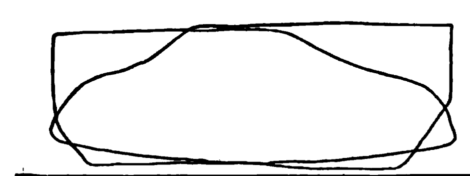
Scale, 40". Air cylinder, 14 x 14. Revolutions per minute, 80.

marked a degree, as the speed is much slower. The air card C was produced at the same time as the steam card D.



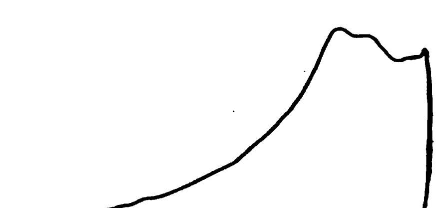
Air Cylinder Diagram (Ingersoll).

Steam cylinder, 10 x 12. Revolutions, 88.
Air cylinder, 12 x 12. Receiver pressure, 68 pounds.
Clearance at each end, 0.026 stroke.



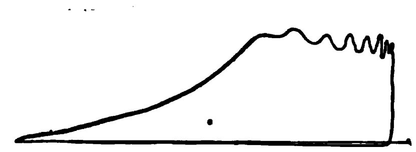
Steam Cylinder Diagram (Ingersoll).

12 x 14. Revolutions, 88.



Air Diagram (Ingersoll).

Steam cylinder, 12 x 4. 62 pounds Receiver pressure. 88 Revolutions.
Air cylinder, 14 x 14. Clearance each end, 0.02 of the stroke.



Ingersoll Air Card.

There are compressors in which the discharge valves are so constructed as to require an excess of pressure above the receiver pressure to start them off their seats. This is due to

the great difference in areas between the openings through the port and the area of the back valve, while the water which is used in the cylinders of some such compressors seals the joint. In card *A* it requires 18 pounds, in *C* $5\frac{3}{4}$ pounds, and in *E* 17 pounds, to get the valve off the seat. As in some of these compressors the discharge valves are heavy blocks, and as these pressures are greater than when the machine moves rapidly, probably the inertia of the valves figures largely in making these high pressures on the diagram. In cards *A*, *C*, *E*, the discharge openings are too small. This is shown in all the air cards, by the fact that the pressure does not fall to the reservoir pressure even after the valve is opened. Of these air cards, *A*, *C*, and *E* show that the cooling arrangements are inadequate. This is shown by the great excess in the pressure of the compression lines over the dotted isothermal line. In *A* the temperature of the middle of the cylinder was 149 degrees, with the air of the room 53 degrees. Of course it is evident that the internal temperatures

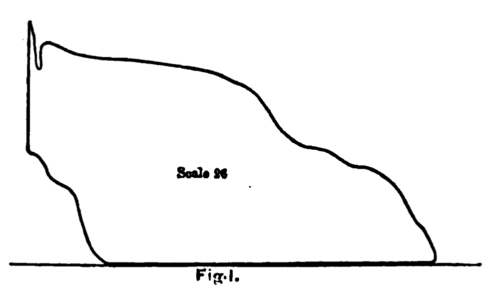


FIG. 1.

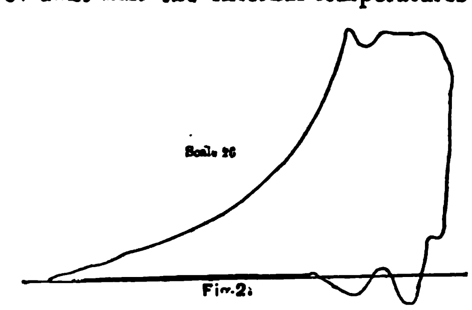


FIG. 2.

were very much higher. In card *E* the cylinder was so hot that the air began to expand immediately after the inlet valve closed and before the piston began to advance.

Cases M and N are offered by the builders of the Allen (High Speed) Compressor, as from a 12 ″ x 12 ″ machine running 144 revolutions per minute. The steam card, M, shows finely as regards absence of counter pressure, but neither the steam line nor expansion curve is creditable; the former indicative of throttling or wire-drawing. The air card, N, is much more satisfactory, showing regular and steady compression and quite prompt opening out, although the lead of the outlet valve, producing the rounded upper corner on the right, is reproduced at the lower right hand corner, showing an early attempt at closing.

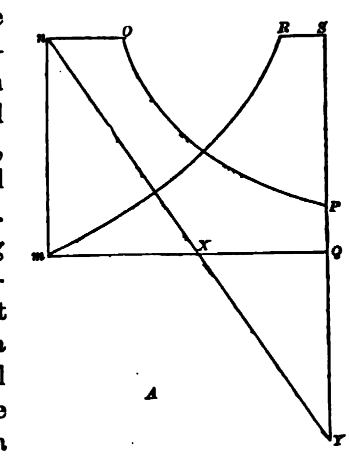


Diagram *A* illustrates the claims made by those advocating high speed with heavy reciprocating parts, to obviate the difficulty arising from the steam and air maxima of pressure being at different ends of the stroke. The steam diagram being *m n O P Q* (cutting off at, say $\frac{1}{4}$), the air diagram, *m R S Q*, will have its greatest height and area opposed to the least in the steam card. By the use of heavy reciprocating parts, the area *m n X* will be used up in quickening these parts during the first half stroke, and the equal area, *X Q Y*, given out as momentum during the latter half of the stroke, to oppose the resistance area at the right hand end of the air card.

Setting Up and Using Compressors.

Where a compressor is to be run by water power, it must be placed near the water-wheel and connected either by strong gears or by well-chosen and well-arranged belts. (Graphite will be found of use in lubricating gears, and castor oil the best thing to prevent leather belts from slipping.) Leather belts are improved by coating their surface with boiled linseed oil. Rubber belts are best for damp places.

Where much air is required, there may be arranged an independent steam-engine with

the main shaft carried out beyond the bearing far enough to have the air-pumps or compressors geared or belted from each side, so that the load shall be as constant as possible. There should be in most cases a reservoir near the compressor, and occasionally it is desirable to have a small one near the delivering end of a long run of pipe.

If the tank be placed horizontally it is best to take the air out either at right angles, or in a reverse direction, to that in which it entered. The larger the pipe, and the fewer and more gradual the turns, the less the friction will be. There should be a valve at the junction of the iron pipe-line and the hose which supplies the drills.

The water used to cool the cylinder, being heated by this action, should be used to feed the boiler, thus retaining some proportion of the heat generated by compression.

As far as possible, air-compressors should be automatic, so that they will start, stop, or alter their speed, according to the quantity of air consumed.

Portable compressors may be made with advantage with the side frames and main portions of the machine of wrought iron instead of cast, thereby avoiding breakage during transportation. For such cases, also, the bed-plate may be hollow; but for permanent work the bed-plate should be solid and massive.

The Efficiency of Air-Compressors.

It is desirable to know just how much of the work done by the steam in the driving engine is spent in compressing the air in the compressor. This is found to be in compressors without piston or plunger, such as Sommeiller's hydraulic machine, less than 50 per cent. In the hydraulic piston or plunger compressor, 90 per cent. has been utilized, where the piston speed was low, and the pressure not above 4 to 5 atmospheres. With external cooling solely, and 4 atmospheres pressure, the efficiency has been found to be 80 per cent. With the Colladon compressor, water spray injection, and piston speed of 345 feet per minute, the efficiency was 80 per cent., with tensions of 8 atmospheres absolute; the air temperature rising from 12 degrees to 15 degrees C. (54 degrees F. to 59 degrees).

Efficiency of compressed air engines, that is, the proportion between the work they do and that which the compressed air ought to give, runs from 50 or 55 in ordinary compressors working against variable resistance, to 70 or 75 per cent. for the very best machines. The efficiency of the whole system, that is, the proportion of the work measured on the crank shaft of the compressing engine, to the work done by the prime mover, is 20 to 25 per cent. for high pressures, and 35 to 40 per cent. for low pressures. At Leeds the net efficiency was ·265 with 2·75 effective atmospheres, and ·455 with 1·33 atmospheres. At Blanzy, Graillot found for final efficiency, ·22 to ·32 per cent. of the effective work of the steam. Ribaurt found the compressed air locomotive of the St. Gothard Tunnel to be 23 per cent. of the original water-power, the loss in this case being from the turbine, the compressor, the expansion regulator, and the locomotive cylinders.

The ratios of full pressure and expansion are laid down by Zahner at about ·27 to ·37 for final efficiency; this being calculated thus:

w' being the work spent upon the air in the compressor, w'' the work which the compressed air had to do, by theory $\frac{w'}{w''}$ will be the theoretical efficiency. w being the actual work done by the prime mover, and w' the actual work done by the air, the real efficiency will be $\frac{w}{w}$. As w' is 70 per cent of w, and w' is 70 per cent of w'', we will have the real effiiciency $\frac{w'}{w}$ to be $\frac{\cdot 70 w^2}{\frac{w'}{\cdot 70}} = \frac{\cdot 49 w}{w'} = \cdot 49 e$.

As e, the theoretical efficiency, is ·55 for full pressure and ·75 for complete expansion, we will have the final efficiency of 27 and 37 per cent.

The following table gives the ratios of efficiency at full pressure to that at complete expansion, at different final degrees C. This table was prepared by Mallard, and reduced by Grimshaw to degrees F. The first column gives the ratios of the final and initial temperatures; the second the final temperature, with complete expansion, in degrees C.; the third the same in degrees F.; the fourth the theoretical efficiency with complete expansion, in per cent.; the fifth and sixth the final temperatures in degrees C. and F., with full pressure; the seventh the theoretical efficiency with full pressure; and the eighth the ratio of efficiency at full pressure to efficiency at complete expansion. In all cases the initial temperature is supposed to be 20 degrees C. (= 68 degrees F.). From this table we can see that by working without expansion we avoid low exhaust temperatures, but get low efficiency. When working at full pressure, the efficiency is lost with the highest working pressure.

MALLARD'S TABLE SHOWING MERITS AND DEMERITS OF FULL PRESSURE AND COMPLETE EXPANSION IN THE USE OF COMPRESSED AIR. ADAPTED TO AMERICAN USAGE BY R. GRIMSHAW.

Pressure Ratios.	Final temperature. Complete Expansion.		Theoretical efficiency with complete expansion.	Final Temperature. Full Pressure.		Theoretical efficiency with full pressure.	Ratio of efficiency at full pressure to efficiency at complete expansion.
2.	33.4° C.	102.02° F.	.855	22.4° C.	72.32° F.	.82	.95
3.	60.0	140.	.806	36.9	98.42	.72	.90
4.	77.0	170.6	.782	43.2	109.76	.67	.86
5.	89.0	192.2	.768	48.0	118.4	.63	.82
6.	98.0	208.4	.758	51.0	123.8	.60	.79
7.	106.0	212.8	.751	53.0	127.4	.57	.74
8.	112.7	234.86	.746	54.5	130.1	.55	.73
9.	118.1	244.58	.742	55.6	132.08	.53	.71
10.	122.9	253.22	.739	56.5	133.7	.51	.69
11.	126.9	260.42	.736	57.4	135.32	.50	.68
12.	130.5	266.9	.734	58.0	136.4	.49	.66
13.	133.8	272.84	.732	58.6	137.48	.48	.65
14.	136.7	278.06	.730	59.2	138.38	.47	.64
15.	139.4	283.02	.729	59.5	139.1	.46	.63

The following table shows the quantity of water at 20 degrees C. (= 68 degrees F.), to be injected in air-compressors, supposing that the water will be increased in temperature 20 degrees C. (= 68 degrees F.) The table, as given by Zahner in kilogrammes, is arranged by Grimshaw for pounds as well; and the equivalent of the calories is given in English heat units or degree pounds.

TABLE FROM ZAHNER, SHOWING AMOUNT OF COLD INJECTION TO KEEP THE TEMPERATURE CONSTANT DURING COMPRESSION.

Absolute pressure to which the air is compressed.	Heat developed by compression, and to be carried off by the injected water.			Weight of water at 20° C. to be injected into the compressor per unit of air compressed in order to keep the final temperature from rising above 40° C.
Atmospheres.	Calories.	English Centigrade Heat Units.	English Fahr. Heat Units.	
2.	14.695	32.329	58.309	.734
3.	23.284	51.224	92.390	1.164
4.	29.392	64.662	116.627	1.469
5.	34.120	75.064	135.888	1.701
6.	37.979	84.553	151.700	1.891
7.	41.264	90.780	163.735	2.063
8.	44.087	96.991	174.937	2.204
9.	46.589	102.495	184.865	2.329
10.	48.816	107.395	193.701	2.440
11.	50.849	111.867	201.768	2.542
12.	52.694	115.926	208.089	2.634
13.	54.391	119.660	215.823	2.719
14.	55.962	123.114	222.057	2.798
15.	57.425	126.335	227.862	2.871

1 Calorie = 2.2 English Centigrade heat units, or 3.968 English Fahr. heat units.
1 English Centigrade heat unit = .454 calorie, or 1.8 English Fahr. heat units.
1 English Fahr. heat unit = .252 calorie, or .555 English Centigrade heat unit.

TABLE FROM ZAHNER, SHOWING LOSS OF WORK DUE TO HEAT OF COMPRESSION.

Tension in Atmospheres.	Compression with temperature constant.				Compression with increase of temperature.						Loss of work due to the heat of Compression.		Fraction of the total work required for compression, which is converted into heat.
	Volume.		Work.		Temperature.		Volume.		Work.				
	Cub. Meters.	Cub. Feet.	Kilo-gram-meters.	Foot Pounds.	Deg. C.	Deg. F.	Cub. Meters.	Cub. Feet.	Kilo-gram-meters.	Foot Pounds.	Kilo-gram-meters.	Foot Pounds.	
1.	1.00	35.8161			20.°	68°	1.	35.8161					
2.	.50	17.658	7,199	52.071	85.5°	185.9°	.612	21.613	7,932	57.732	733	5301.862	.092
3.	.333	11.775	11,856	82.139	130.4°	266.72°	.459	16.210	13,360	96.634	2,004	14495.132	.150
4.	.250	8.829	14,260	103.144	165.6°	330.08°	.374	13.208	17,737	128.293	3,477	25149.488	.196
5.	.200	7.063	16,580	119.924	195.3°	383.54°	.320	11.301	21,209	153.406	4,629	33482.019	.213
6.	.167	5.897	18,475	133.631	220.5°	428.9°	.218	9.923	24,310	175.836	5,835	42205.138	.240
7.	.143	5.050	20,038	144.936	243.2°	469.76°	.252	8.890	27,048	195.639	7,040	50921.024	.260
8.	.125	4.414	21,422	154.947	263.6°	506.48°	.229	8.087	29,518	213.406	8,096	58559.177	.274

LOSS IN TRANSMISSION OF COMPRESSED AIR.

At the Mont Cenis Tunnel the compressed air was carried in cast-iron pipes, $7\frac{5}{8}$ inches in diameter. The loss of pressure and air leakage in one mile and 15 yards was only $3\frac{1}{2}$ per cent. of the head, an expenditure of 64 cubic feet per minute of compressed air running the absolute initial pressure from 5·70 atmospheres to 5·50 atmospheres. In the middle of the tunnel the absolute pressure, after 3·8 miles, fell from 6 atmospheres to 5·7, or 5 per cent. loss.

The loss of pressure varies directly as the length of pipe; directly as the square of the velocity of the air in the pipe, and inversely as the diameter of the pipe. There is some gain by the difference of level between the compressor and the drill in many tunnels and mountains. (See pp. 136, 308, and 364.)

TABLE OF OBSERVED AND CALCULATED VELOCITIES OF COMPRESSED AIR AT THE EXIT FROM LONG PIPES.

(In paper by S. W. Robinson, *Van Nostrand's Magazine*, May, 1881, p. 377.)

Experiments.	Absolute.		d	l	t	f	Velocity, u_2.		Diff.
	P_1	P_1-P_2					Calc'd.	Obs'd.	
	lbs.	lbs.	inches.	ft.	Fahr.				
From experiments made by order of the Italian government, preliminary to use of compressed air in the Mount Cenis Tunnel.	90.	.117	8.937	3281	520	.006	3.12	3.28	−.16
	....	.516	....	....	....	....	6.58	6.56	+.02
	....	1.218	....	....	....	....	10.18	9.84	+.34
	....	....	....	....	....	...	13.54	13.12	+.42
	....	....	....	....	....	....	17.01	16.40	+.61
	....	....	....	....	....	....	20.29	19.68	+.61
	90.	.062	7.875	3281	520	.006	3.22	3.28	−.06
	....	....	....	....	...	....	6.55	6.56	−.01
	....	....	....	....	....	....	10.12	9.84	+.28
	....	....	....	....	....	....	13.41	13.12	+.29
	....	....	....	...	....	....	16.64	16.40	+.24
	....	....	....	....	....	....	19.96	19.68	+.28
	90.	.039	13.75	3281	520	.006	3.37	3.28	+.09
	....	....	....	....	....	....	6.74	5.56	+.18
	....	....	....	....	....	....	10.14	9.84	+.30
	....	....	....	....	....	....	13.23	13.12	+.11
	....	....	....	....	....	....	16.71	16.40	+.31
	....	....	....	....	....	....	19.80	19.68	+.12
Experiments of Wm. S. Henson, at Bloomingdale, N. J., for Mr. H. H. Day. Vol. 4, p. 205.	37.00	12.0	1.25	5280	520	.006	29.50	29.40	+.10
	43.00	8.	....	....	....	....	19.30	20.00	−.70
	50.25	5.25	....	....	...	....	13.27	15.10	−1.83
	58.25	3.25	....	....	....	....	9.43	11.75	−2.32
	66.75	1.75	....	....	....	....	6.31	9.60	−3.29
Experiments at St. Gothard Tunnel. Vol. 24, p. 96.	82.32	5.29	7.87	15,092	531	.006	15.32	19.99	−4.67
	63.94	3.23	....	....	....	....	13.42	16.73	−3.31
	56.45	2.79	....	....	....	....	13.29	15.97	−2.68
	77.03	3.53	5.90	1719	541	.006	33.04	38.05	−5.01
	60.71	1.03	....	....	....	...	19.38	30.81	−11.43
	53.65	1.54	....	....	....	....	25.53	29.76	−4.23

The following table gives the stated capacities of the Clayton Duplex Compressor, for working rock-drills and coal-cutting machines.

Size by Numbers.	Diameter of Steam Cylinders in inches.	Diameter of Air Cylinders in inches.	Length of Stroke.	Number of Revolutions per minute.	Cubic feet of free air Compressed per minute.	Approx. weight of Compressor in pounds.	Compressor will furnish plenty of air to run following number of 3-inch rock drills at 60 pounds pressure.
1	8	8	12	120 to 140	165	3,000	2 Rock Drills.
2	9	9	13	120 to 130	180	5,000	3 " "
2½	10	10	13	100 to 130	206	7,000	4 " "
3½	12	12	13	100 to 130	300	10,000	6 " "
4	14	14	15	100 to 120	450	15,000	8 " "
5	16	16	15	90 to 100	625	17,000	10 " "
6	16	16	20	90 to 100	837	20,000	14 " "
7	18	18	24	80 to 90	1128	25,000	20 " "
8	20	22	24	70 to 80	1600	35,000	
9	22	24	30	70 to 80	2600	45,000	
For working coal-cutting machines.	7	8	12	120 to 140	165	2,700	2 Coal Cutters.
	8	9	13	120 to 130	180	4,500	3 " "
	9	10	13	100 to 130	206	6,500	3 " "
	10	12	13	100 to 130	300	9,000	4 " "
	12	14	15	100 to 120	450	13,000	7 " "
	14	16	15	90 to 100	625	16,000	9 " "
	14	16	20	90 to 100	837	18,000	13 " "
	16	18	24	80 to 90	1128	22,000	17 " "
	20	22	24	70 to 80	1600	35,000	
	22	24	30	70 to 80	2600	45,000	

At Marquette, Mich., the Republic Iron Co. has substituted for steam, compressed air taken about a mile from the works, the compressor being driven by water power. There are 4 machines, 24 x 60 inch, driven by two 5½ foot Swain turbines under 16 feet head, rated at 450 HP. The air pipe is of boiler iron, and 15 inches inside diameter. The mines and shops are said to obtain 66 per cent. of the effective power of the wheels.

In the matter of lubricating air compressors, James Barr, chief engineer of the Iago mines, Sinaloa, Mexico, writes to the San Francisco *Mining and Scientific Press* (see No. for Sept. 10, p. 170), that he is using Grixby's system upon a double cylinder 16 inch bore compressor, giving perfect lubrication, and leaving the inside of the cylinder bright as a mirror, no rust or corrosion anywhere. Mr. Barr says that the same leathers that have been in constant use for over 9 months on the valves are still perfectly good, and to all appearances will last for many months to come. The consumption of oil is $\frac{1}{1000}$ [?]. He states that the steam cylinder on the machine will furnish plenty of condensed water from the bibb cocks alone to run two such compressors. He says that the saving per year will reach $150 on oil, $550 on fuel, $800 on water, and $100 on lost time and repairs per year; giving a total yearly saving of $2,500.

Abstract of certain American Air Compressor Patents.

Aug. 14, 1877, No. 194,217.—Henry Bushell, New Haven, Conn. Reservoir for compressed air. Lap-welded tube with solid heads welded in place. Two or more may be combined by a block or casting to which the tubes are connected by bolts.

Oct. 16, 1877, No. 196,253.—Jno. B. Root, Port Chester, N. Y. Air compressor. This is for the purpose of obtaining sensible heat from cheap power derived from natural sources. When a permanent gas is compressed, some of its specific heat is rendered sensible, and may be transferred by radiation or other methods. The greater the compression the greater the elevation of temperature and the larger the amount of sensible heat available. The gas, after giving out this heat, has an expansive force, and can be used for the purpose of doing work.

In so doing work, its temperature falls, and it will extract heat from other bodies. In Root's patent these forces are utilized; there is nothing special in the apparatus themselves.

Dec. 12, 1877, No. 198,067.—B. T. Babbitt, New York city. Hydraulic displacement air compressor. Duplicate air compressing cylinders or tubes are controlled by balanced valves, to admit the water or air alternately into a trunk or chute, with duplicate discharge valves. All the valves are operated by floats in the two compressing chambers.

Sept. 10, 1878, No. 207,954.—Willard D. Doremus, Washington, D. C. Displacement air compressor. Two rocking receivers connected by air and water pipes with a hollow sleeve and a hollow axle, having inlet ports, and upon which the sleeve turns. Water being admitted under pressure, the receivers alternately receive water and discharge air. (Bellows device.)

Dec. 4, 1878, No. 211,570.—Moses Harvey, Leavenworth, Kansas. Air compressor. Two hollow pistons, placed end, to end with a yoke block between them by which they are reciprocated, move in stationary cylinders communicating with an air receiver above. The spaces in the cylinders and pistons are nearly filled with water when the pistons are at mid-stroke, and the motion of the pistons drives the water and air alternately from one cylinder or the other to the receiver. The air inlet valves serve also for the admission of spray of cooling water, and are in the center of the outer cylinder heads.

April 15, 1879, No. 214,465.—Allen Spencer, Columbus, Ohio. Air compressors for pneumatic dental pluggers. Rubber bulb under a treadle.

April 29, 1879, No. 214,769.—Wm. F. Garrison, Brooklyn, N. Y. Air and gas compressor. Steam cylinder is between and in the same line with two single acting air cylinders. Discharge valve is a piston of the same diameter as the compressing piston, by which it is pushed back, allowing the air to escape into the annular passage around the air compressor cylinder. The air inlet valve is contained within the discharge valve.

May 20, 1879, No. 215,540.—Jno. B. Pitchford, Gold Hill, Nev. Air compressor. No water is let into the air cylinder unless the compressor is working, and not then unless the air valve opens. The piston has brass rings and hemp packing, combined so as to carry moisture all around the piston by capillary attraction.

July 22, 1879, No. 217,834.—William Thomas, Jersey City, N. J. Hydraulic air compressor. Combination of an oscillating float and the lost motion oscillating weight for water valves at the proper

July 29, 1879, No. 217,965.—Jno. B. Waring, New York city. Air compressor. There is an inner and an outer cylinder, both exposed to cooling influences, combined with a reciprocating annular piston adapted to the compressing chamber between the two cylinders. The cooling is done preferably by spiral passages in water jackets. There is a hollow piston to the inner cylinder.

Aug. 28, 1879, No. 221,126.—Jno. Trent, New York, N. Y. Hydraulic air compressor for domestic purposes.

Nov. 14, 1879, No. 221,318.—Wm. Johnston, Washington, D. C. Air compressor. Fixed shaft or bearing; cylindrical casing inclosed at its ends, journaled upon this shaft, and having within its upper portion valve chambers with inlet and outlet valves, and extending down to the upper side of shaft; fixed partition extending between the lower side of the latter and the lower wall of the casing, filling the lower half of the casing. Valve chambers have their side walls formed upon radial lines at angles of 60 degrees, and acting as pistons.

Nov. 18, 1879, No. 221,802.—William Gardner, New York city. Air compressor. Lager beer arrangement.

Nov. 25, 1879, No. 222,014.—James Clayton, Brooklyn, N. Y. Air compressor. To obviate the trouble of water jacket cylinders, that the cylinder gets hottest near the ends, by

reason of the air being at its greatest pressure at the end of the stroke of the piston, thereby binding at the middle of the stroke and leaking at the ends. He has the inlets of his water jackets near the ends of the cylinder, and the water outlet at the middle of the cylinder.

Dec. 28, 1879, No. 222,802.—William P. Tatham, Philadelphia. Air compressor. The steam and air piston have a double-armed rock shaft, with its arms connected with the rods of the steam and air piston, so that the compression is effected under the decreasing leverage of the rock shaft arm and the correspondingly increasing leverage of the arm of the steam piston. As the first or power arm moves from near its dead point to its point of greatest leverage and power, the second or resistance arm correspondingly moves from its point of greatest to its point of least leverage and resistance. The steam cylinders are single acting.

Feb. 3, 1880, No. 224,081.—William R. Eckart, Virginia City, Nev. Cooling device for air compressor. As the piston approaches one end of the cylinder, a spray of water is discharged from a nozzle in the piston. The piston is hollow, the piston rod solid, the water being brought in by a rigid perforated tube which passes through a stuffing box in one end of the cylinder heads, and enters the hollow piston head. The spray is continuous, and in both ends of the cylinder at the same time.

Mar. 13, 1880, No. 227,877.—Jas. M. Bois, Aurora, N. Y. Hydraulic air compressor. There are two combined air and water tanks, which are alternately emptied and filled from a large reservoir through two flumes automatically opened and closed by gates operated by floats.

June 29, 1880, No. 229,468.—Henry Richmann, San Francisco. Peculiarly shaped crane for carrying power from the steam cylinder to the air compressor. The crank for the cross slide of the steam cylinder is in one piece with that for the air cylinder. The air and steam cylinders have double piston rods, to get better balance and leave more room for large valves in the cylinder heads. The pillars and bed pieces are hollow and act as the air reservoir. The two cylinders are so nearly in line that one set of guides answers for both. There is a three-armed double crank of peculiar construction in this machine; the air cylinder is water jacketed.

Feb. 1, 1881, No. 237,274.—Hill's patent is for the use of two or more compression pumps in combination with a steam or smaller engine (where a high degree of compression is desired), and consists in combining an automatic governing apparatus between two compression pumps of different capacities, so that air or gas under pressure from the larger may be conducted to the smaller pump and again compressed to any desired degree at which the regulator may be set. In this patent there is a supplemental pump which will, when desired, furnish extra pressure and power required for this special working. The supplemental pump is arranged beside the regular compressing pump, its piston rod being attached to a projection from the cross-head of the other pump, but a connecting pipe leading from the first to the second pump, having in it a valve which, when closed, will prevent the passage of air from the larger to the smaller pumps, and provided with a stem and lever. To this lever there is a piston working in a short cylinder, the lower end of which is in communication with the discharge side of the supplemental compressor, so that if there be a pressure in the pipes or reservoirs on the discharge side of the supplemental compressor, it will tend to raise the lever and close the valve, thus causing the piston of the supplemental pump to work in vacuo, or nearly so. But when there is a demand made upon the reservoir attached to the supplemental pump, then the pressure under the piston will fall, the valve be opened, and compressed air from the larger pump will be furnished to the supplemental pump to be still further compressed.

Abstracts of certain English Patents.

May 22, 1876, No. 2189.—Victor C. J. Ortmans, Brussels. Rotary pumps. Circular

shell having inlet and outlet pipes. Body wider at the rim than at the centre. Rotating disc having four depressions, each of which is fitted with a butterfly valve upon a spindle or axis crossing the middle of the depression radially to the centre of the plate. Fore side of each valve is heavier than the rear side. An obturator is formed of two solid portions projecting one from each side of the chamber; the ends being curved to shut the valves.

Jan. 3, 1877, No. 39.—Jno. Shaw, Ovenden, near Halifax, York, and William Timbrel Clark, Queensbury, near Halifax. Apparatus for compressing or forcing air. Inlet valve operated by hydraulic cylinder and piston, cylinder being attached to the piston rod or other moving part of the compressor; hydraulic piston connected to a cross-head to which the valve spindle is attached, or same piston and cylinder may work by vacuum instead of by liquid. Or steam cylinder and piston in conjunction with or independent of the moving parts of the compressor. Or valve may be operated by eccentrics; or having small cylinder and piston to each inlet valve, this may be operated by compressed air from the compressor. Or the valves may be worked by tappets upon the piston rod. Or there may be a rack upon the piston rod, gearing with a pinion having a stud to operate the valves. Outlet valves may be closed by pins and levers, or by friction.

Sept. 25, 1877, No. 3,599.—Jno. Edward Stokes, Upton Manor, Essex. Air compressor. Series of inlet valves and cylinders in the outside covers of the main cylinder, free from springs. Small cylinders have centre guides for the valves. Inlet valves are horizontal; outlet valves are in small vertical cylinders on the top of the main cylinder, and are adjustable by set screws.

Sept. 28, 1877, No. 3,633.—Sydney Pitt. Communication from Thos. Fitch Rowland, Green Point, L. I. Apparatus for transmitting compressed air to moving machines. Automatic air-tight drum carrying a flexible tube, and automatic apparatus for winding and unwinding the tube; air enters the axle of this drum. Rotation is by a cord and weight.

April 10, 1877, No. 1,396.—George Henry Fish, Memberton. Apparatus for compressing air. Induction valve worked by positive means. Induction valve is annular or cylindrical, and smaller than the inside of the cylinder. In the openings passing through the cylinder ends, and being in a circle just inside the inner circumference of the cylinder piston, a hollow cylinder open at each end, but with a solid disc in the centre. Open cylindrical ends pass between the cylinder walls and the exterior of the induction valve, which has a rubber friction ring to cause drag between the piston and the inner edge of the valve. Outer edge of the valve has rods passing through the induction openings, and each connected to a lever arranged radially to the cylinder, having inner ends close to the piston rod and fulcra midway. A tight collar upon the piston rod acts upon these levers. Delivery valves are radially around the circumference of the cylinder at each end. There is a central valve at each end in the cylinder, close around the piston rod. Side openings in the open cylindrical ends of the piston correspond with the radial delivery openings. Motion of piston drags induction valve, by friction of collar upon the piston rod, closes it by the levers.

Jan. 17, 1878, No. 228.—John Ramsbottom, Leeds. Obtaining motive power from liquids and gaseous fluids, and for pumping and compressing. Cylinder bottom is cylindrically concave and oscillates upon a parted cylindrically convex valve boxes, and divided equally lengthwise by radial mid feathers, the bottom of which forms the center of oscillation. Beneath this line of length there is a tension plate, to which the cylinders are bound by adjustable bolts.

Jan. 30, 1878, No. 390.—William Morgan Brown, 38 Southampton Buildings, London. Communication from Geo. F. Blake, Boston, U. S. A. Steam pumps for compressing or exhausting air. Valve plate bearing inlet and discharge valves between flanged top, having inlet and discharge openings and flanged fluid chamber, all bolted together. Openings in the

top of the fluid chamber connecting with the valves by channel ways to prevent material connected and expel all material pumped. Inlet valves open downward; discharge valves upward. Piston rod has an adjustable bushing, which may be turned to allow for wear. Rubber valve having under surface concave from edge to centre, and centre held so that central portion of the face will set later than outer portion.

Jan. 17, 1878, No. 228.—Jno. Ramsbottom, Leeds. Oscillating motors, pumps, and compressors.

April 5, 1878, No. 1,361.—Edgar Gaylord Wheeler, Strand, London. Compressor. (Provisional protection only.) Inlet and delivery valves have flat faces and flat seatings, and the opening through the thickness of metal is filled by a projection or boss on the valve below. The seating of an angular or conical form, so that when the valve is down the whole space is filled up, and when the valve is lifted there is enlarged space for the passage of the gas or air. There is very little piston clearance and the piston head is faced with india rubber; or there may be a powerful spring outside the cylinder in connection with the cross head. Piston rings are self-expanding by pressure from the end rubber discs. Any leakage past the ram piston leaks into the outer air and not into the intake side. Glands are packed by glycerine under hydraulic pressure applied by a weight or plunger. Or gland may be packed by thin sheet of metal bent around the rod or ram, outside of which there is a rubber ring; screwing up the edge of the ring swelling up the rubber and pressing the metal closer around the rod or ram.

Oct. 4, 1878, No. 3,917.—John Henry Johnson, 47 Lincoln's Inn Fields, London. Apparatus for compressing ammonia and other gases. Two plungers connected and operated by connecting rod and cross-head. Between cross-head and arm there is elastic material. All valves are in the middle of the cylinder head and closed by springs. In one arrangement, the cylinder head forms a seat for a spring outlet valve carried upon a tubular stem sliding in the valve cylinder. Induction valve is in the centre of the outlet valve. The pump cylinders are grooved for packing rings, or for glycerine and plumbago.

Oct. 15, 1878, No. 3,223.—Jas. Gaddon, 22 Castelnau Villas, Barnes, Surrey. Sucking, compressing, and discharging fluids. Series of pumps at any angle, moved by a series of tappets, and wheels mounted on a shaft; pistons being returned by springs. Tappets are arranged in the form of a screw.

March 26, 1879, No. 1,200.—Wm. Henry Northcott, No. 8 Union Court, London, E. C. Piston of main cylinder is prolonged to form a second and smaller cylinder. Air drawn into the main cylinder by the motion of the main piston in one direction, is forced into the smaller cylinder during the return stroke, and there further compressed by a stationary piston upon which the second cylinder works. Air cooled by a water coil between the stages of the compression, as well as after. Water jacket or injection. Safety valve upon water coil.

April 30, 1879, No. 1,701.—Thos. Cartledge, Manchester. Compressing and condensing air. Series of air pumps of gradually diminishing area and increasing strength. (It will be noticed that this patent claims stage pumping, already long known and practiced.)

July 21, 1879, No. 2,960.—Edmund Edwards, 40 Southampton Bridge, London. Communication from Edouard Reyer, Vienna. Compressing and exhausting air. (Provisional only.) Two closed vessels connected to water supply, by a 4-way cock; one fills as the other discharges. Amount of compression depends upon height of column of water in one column; amount of exhaustion, upon length of the other pipe going into the cistern below.

Literature of Air-Compressors.

André on "Coal-Mining," p. 169. This discussion in Mr. André's work is full and most excellent.

Paper on the "Production and Use of Compressed Air in Mining Operations," by N. F. L. Cornet. See "Journal of the Franklin Institute," Philadelphia, June and July, 1877.

"English Mechanic and World of Science," vol. xxii., p. 406.

"Scientific American," for April 29th, 1876, p. 277.

"Engineering," vol. xii., pp. 193, 241 (1871), and vol. xiii., p. 86 (1872).

"Notes on Work Performed by Compressed Air," by M. L. Trasenter. Paper before the Liège section of the Association of Engineers. See "Universal Review of Mining," etc. (English edition of the "Revue Universelle des Mines," etc.) London and Liège, March, 1874.

Report by Prof. A. Habets on "*Exploitation des Mines,*" at the Vienna Exhibition. "*Revue Universelle des Mines,*" etc., vol. xxxvi., 1re *livraison*, July and August, 1874. (This has also been republished in separate form. See "*Revue Universelle,*" vol. xxxix., 3me *livraison*, June, 1876.)

Paper on "The Performance of Compressed Air applied to the Transmission of Mechanical Work," by Paul Piccard. See "Minutes of the Proceedings of the Institution of Civil Engineers," vol., xlv., p. 273 (Session 1875–'76); also for the same paper, "*Bulletin de la Société Vaudoise des Ingénieurs et des Architectes,*" for 1876, p. 10.

"*L'Air Comprimé et ses Applications,*" by M. A. Pernolet, Paris, Dunod, 49 Quai des Augustins, 1876.

Paper on "Air Compressors," read before the Franklin Institute, by Robert Grimshaw, Ph.D., abstract published in "Journal of Franklin Institute," June, 1881.

Notes on "Air Compressors," by R. Grimshaw, running through various numbers of the Pittsburgh "Brick, Tile, and Metal Review," August, 1881, *et seq.*

Rapports trimestriels du conseil fédéral suisse aux gouvernments des états qui ont participés à la ligne du St. Gothard. Berne; Librairie J. Dalp.

Transmission of Power by Compressed Air—Robert Zahner. Van Nostrand's Science Series, *40, 1878; 132 pp., 18mo.

The first mention of the art of boring was in a book published by C. T. Delius, in Venice, 1770. The art was doubtless invented by the Chinese, and brought to Europe by Jobard. There are two ways, one by rigid rods and the other with a rope. There are two distinct operations—first, the raising and letting fall of some heavy tool into the bottom of the bore hole, cutting up and breaking the rock into small pieces, and second, raising the débris or sludge from the bottom of the hole. On the Continent all the deep borings are generally carried on by the aid of the boring lever. The breakage of the shaft rods, especially at their screw joints, is a constant occurrence in deep holes. It is necessary that the rods be light and stiff, hence wooden rods are often used, especially where the bore hole is full of water. In 1840 Kind invented the lengthening screw, which has superseded the chain in deep borings. There are two long side links held together at the top by a pin, the nuts screwing on at the ends outside the links. In 1831 borings were commenced at Neusalswerk, Westphalia, for salt, under the direction of Von Ocynhausin. In 1834, 900 feet had been reached, but there were found unsurmountable obstacles, although there were 1,300 feet more to be done. Then the engineer conceived the idea of detaching the lower parts of the rods, and invented the sliding shears or jaws. Kind's free falling boring rod was employed for the first time in 1844, at Mondorf, between France and Luxembourg. There are two principal parts of the free falling instrument—the free falling rod and the shears. The rod has at its upper extremity a small tongue piece about 2 inches long, 1½ inches wide, and 1⅝ inches broad, the bottom of the rod being ⅝ inch broad and 1½ inches wide just below the tongue. About 12 inches lower down there are inserted two nose pins of steel, the bottom of the falling rod terminating in a cylindrical portion or neck, to which the lower rods of the boring chisel can be secured.

PART II.

Machine Rock-Drills *—their History and Characteristics.

We have seen in Chapter II. the successive dates in the history of explosives, rock-drilling, and blasting; how gunpowder was invented by Berthold Schwartz, in 1320, and how blasting was first applied in mining by Martin Weigel, in the Freiberg mines, in 1613. Also that in 1683, Henning Huthmann, rector of Ilefeld, proposed the first "boring-machine," † a drop-drill in fact, as it is said it was to be raised by a rope drawn by two men and then dropped. This drill, according to Calvör (1763), with ten blows would sink a hole one and a half inches deep, and a hand's breadth wide and long. (There is a copy of Calvör's work in Mr. Eckley B. Coxe's library at Drifton, Pa.) Further that, in 1721, Barthels, of Tellersfeld, ‡ is said to have invented a machine for drilling or boring (also said to be for shafts, probably a drop-drill), and that in 1803 a machine, said to work "quicker than a miner," was made by Gainschnigg,§ at Salzburg. (See also for early data, *ante*, p. 188.)

In 1813, Richard Trevethick, the distinguished English engineer, is said to have *suggested* rock-drilling by machinery. ‖

In 1838, ¶ J. M. and John A. Singer ** experimented with a large drop-drill on Section 54 of the Illinois and Michigan Canal, about thirty miles below Chicago. This machine was patented in May, 1839, and some ten or twelve machines were built for and used upon the canal, until the suspension of that work in 1841–'42. They were also used in the Mount Washington Cut, near Hinsdale, for the Western Railroad of Massachusetts. Two machines were built at Lockport, in 1840, and used upon the enlargement of the Erie Canal. Modifications of these machines are still in use in various parts of the country. They are all drop-drills, and their operation is restricted to vertical holes. (There have also been many patents taken out for hand-drills (see p. 259). As there seems little likelihood of the latter ever coming into general practical use, they have not been treated of in this work, though the number of patents taken out for drills of this description would indicate the attention given to their study. From 1852 to 1876 inclusive, there were some eighty patents issued for them in the United States.) The original Singer drill, as used in Illinois, is considered to have been the first successful machine for its purpose.

In 1840, bore-holes were made with a rotary borer †† at Lankowits, in Styria, for drill-

* The name "rock-drill" is in most cases a misnomer, as the devices used for perforating rock very seldom have a drilling action proper. The French word "*perforatrice*," or perforator, is used with better reason. However, there is little more use in calling attention to this fact, than in stating our use of the word fore-plane as incorrect and the English use correct; the English meaning by fore-plane what we call a jack-plane, which is really the *before* plane.

† Ržiha, "*Eisenbahn-Unter-und Oberbau*," p. 350; also Stapff, "*Ueber Gesteinbohrmaschinen*," p. 2, footnote, and Ržiha, "*Tunnelbaukunst*," vol. i., p. 131.

‡ Stapff, p. 2.

§ Ržiha "*Tunnelbaukunst*," p. 131; also Ržiha "*Eisenbahn-Unter- und Oberbau*," p. 350; Moll's *Annalen*, vol. ii., p. 300 (1803); Stapff, p. 42.

‖ Ržiha, "*Eisenbahn-Unter- und Oberbau*," p. 350.

¶ R. W. Raymond, "United States Mining Statistics," 1870, p. 503.

** It is an interesting fact (though one hardly collateral to rock-drilling) to note that the well known "Singer sewing-machine" was invented by one of these men.

†† Stapff, "*Ueber Gesteinbohrmaschinen*," p. 220.

ing holes in lignite. Fig. 79 shows an illustration of one. Similar appliances were also used a little later in the gypsum quarries of Paris. Another was used in the slate quarries of Rimogne.* Kranner used rotary drills for making stone water-pipe in Prague, in 1845, and later he used them in boring limestone during the construction of the Karst Railroad in 1853–'57.† Later, the rotary borer was applied to a steam-drill (Schwarzkopff's drill, 1857, Fig. 80.) This latter was tried at the Mont Cenis Tunnel. (The later De la Roche Tolay

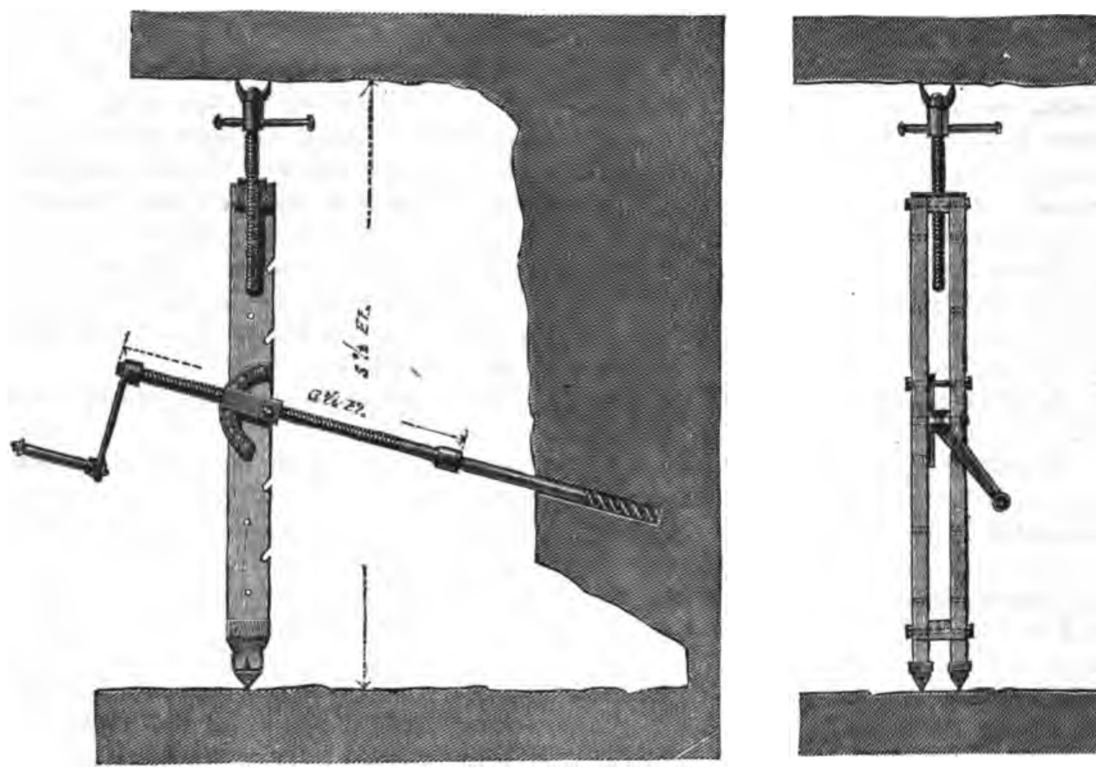


FIG. 79.

ROTARY BORER FOR LIGNITE OR ANY EASY MATERIAL.

drill is also of this type. In the latter, instead of a steel drill-point, diamonds were set in the rotary borer. It was, in fact, an application of the ordinary diamond-drill principle.)

In 1844, Brunton proposed using compressed air‡ for working drill-hammers, the air after use to serve in ventilating. Compressed air had long before been tried for machinery (see p. 135), but this seems to have been the first proposal to apply it to its great modern use.

In this connection, also, Nasmyth's borer may perhaps be noted. It was described by Mr. Nasmyth before the British Association for the Advancement of Science, at the Liverpool meeting in 1854, and Mr. Nasmyth's remarks are reported as follows:§ "In the ordinary method of boring holes for blasting, by striking at the end of the bar with heavy

* Stapff, "Ueber Gesteinbohrmaschinen," p. 221.

† Rziha, "Tunnelbaukunst," vol. i., p. 132.

‡ Rziha, "Tunnelbaukunst," vol. i., p. 132; Rziha, "Eisenbahn- Unter- und Oberbau," vol. i., p. 351.

§ "Civil Engineers and Architects' Journal," vol. xvii., p. 400.

hammers, a great portion of the effect is lost by what is commonly called the 'inertia' of the bar. To overcome this defect, Mr. Nasmyth proposed to convert the bar into a piston-rod, to work in an air-tight cylinder through a stuffing-box. By this means, when the piston is drawn to the end of the cylinder, the pressure of the atmosphere will force it back again with accumulating velocity, and the blow struck will have much greater effect. Mechanical contrivances might be introduced for changing the shape and the direction of the penetrating point. The bar could be drawn to the end of the cylinder by any convenient application of mechanical power. The annexed wood-cut (Fig. 81) represents the form of the boring apparatus, as sketched by Mr. Nasmyth. It was suggested, in the discussion that ensued, that a similar effect might be more readily produced by the employment of vulcanized india-rubber springs. Mr. Nasmyth observed that any elastic medium would answer the purpose, but air suggested itself as affording greater extent of spring."

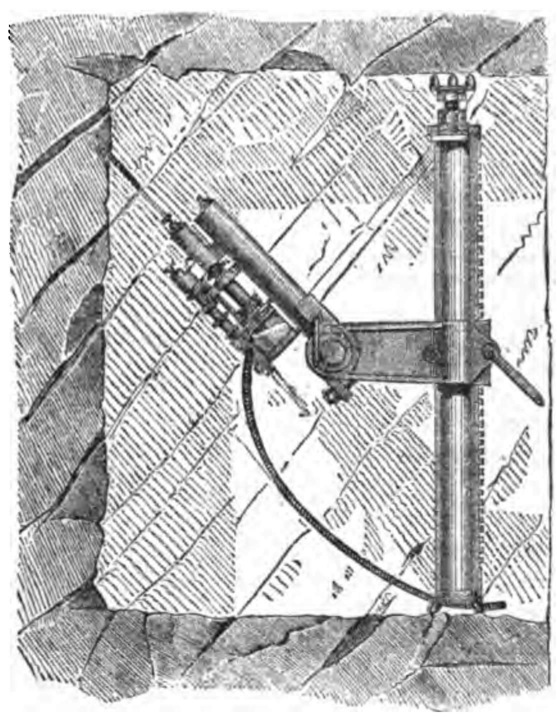


FIG. 80.

SCHWARZKOPFF'S ROTARY DRILL.

(Tried at Mt. Cenis Tunnel.)

Nasmyth's steam forge-hammer (patented December 2d, 1844), also proposed for breaking stone, was a step, though a false one, in the history of rock excavation. This hammer, in a modified form, was subsequently used in the gypsum quarries of Marcousis near Paris. It is said that here the nearest approach to a percussion-drill was attained short of the true invention, as the attaching of a tool to the hammer was tried. The motor (steam), however, was only applied on one side of the piston, and there was no provision for rotating the drill.*

In 1845, Mauss first proposed his rock-cutting machine (worked by revolving cutters) for use at the then proposed Mont Cenis Tunnel. He, however, did not perfect his plan until 1849, and in 1850 it was abandoned as impracticable.† All these attempts, however, had not reached the stage of the machine rock-drill as we now know it. The idea of full area tunnel-machines, or machines designed to cut out a smaller core as a heading, originated by Mauss, was very generally discussed. Patents for machines of this description have been taken out both in England and the United States. Brunton's tunneling-machine for boring through chalk, proposed for use in the Channel Tunnel, is the latest production. Among other English patents in this direction have been the following:

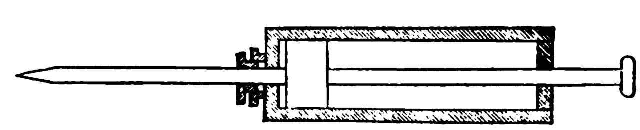


FIG. 81.

NASMYTH'S BORER.

* Stapff, "Ueber Gesteinbohrmaschinen," pp. 2 and 53.
† Rziha, "Tunnelbaukunst," vol. i., p. 132.

TABLE 19.

ENGLISH PATENTS FOR MACHINES TAKING OUT FULL AREA ATTACKED.

DATE AND NUMBER.	NAME OF INVENTOR AND BRIEF OF PATENT.	PUBLISHED DESCRIPTIONS.
March 29th, 1856. No. 760.	**H. N. PENRICE.**—Cuts tunnel full size. Rotation by worm-gear; valve operated directly by tappet. This machine is distinguished by having in its specifications what is, in fact, the first claim for a tappet on a rock-cutting machine.	See "The Engineer," vol. vii., p. 426, June 17th, 1859. Description with illustrations.
July 30th, 1864. No. 1904.	**F. E. B. BEAUMONT.**—Gang of cutters; supplementary valve; tappet and annular projection; hand feed; rotation automatic by worm and feather.	
August 26th, 1870. No. 2349.	**T. F. HENLEY.**—Cuts tunnel full size.	"Engineering," vol. ii., p. 22, January 13th, 1871. Full description with illustrations.
June 20th, 1871. No. 1612.	**E. A. COWPER.**—Several machines mounted on trunnions; cuts drifts full size.	
1875. No. 2999.	**PENRICE.**—For rock-tunneling and shaft-sinking.	
1875. No. 4166.	**F. E. B. BEAUMONT.**—Tunnel-driving machine.	

In America, the Hoosac Tunnel, as in Europe the Mont Cenis, set the minds of inventors to work on designing tunneling-machines. One was constructed in South Boston, in 1851, especially for the Hoosac Tunnel, which weighed about 70 tons, and was designed to cut out a groove around the circumference of the tunnel 13 inches wide and 24 feet in diameter, by means of revolving cutters. The central core left was to be subsequently blasted by gunpowder. On March 23d, 1853, Mr. A. F. Edwards, the first engineer in charge of Hoosac Tunnel, testified as follows before the Joint Special Committee of the Legislature of Massachusetts, as to this machine:

"Again, from the time the charter was granted to the Troy and Greenfield Railroad, when the feasibility of tunneling the Hoosac Mountain was settled by the people in the act of the Legislature of Massachusetts, beyond a possibility of doubt, the mechanical and engineering talent of the Yankee combined have been turned to the most economical method for its construction, in the shortest possible time. And among the various improvements in machinery for drilling stone and making excavations, no machine at the present day should command the attention of railroad men more than Wilson's patent stone-cutting machine for tunnel excavation in rock; the first working model, of 100 tons weight, is now at the Hoosac Mountain, experimenting in various ways, and perfecting the principles of the same. The result of its workings in the natural rock, under every disadvantage, in the different experiments, has been from 14 to 24 inches forward per hour, on a full circle of 24 feet diameter; exceeding the expectations of its most sanguine friends, and bidding fair to revolutionize the whole system of railroad-building. At the view, by the committee of the Massachusetts Legislature, of the working of the model, under many disadvantages, the machine cut the rock at the rate of 1½ lineal feet per hour, with the thermometer at only two degrees above zero, on that morning, although exposed in the open air, with all its cast-

iron fixtures, which should be of wrought-iron. The machine has never worked less than 14 inches per hour. To show with what progress this tunnel could be worked, I will say the machine will cut 12 inches per hour, 33⅓ per cent less than was actually witnessed by the committee of the Legislature. In two hours the machine will cut, at that rate, 2 feet forward; the ring of the tunnel (of which the diameter is 24 feet, interior diameter of the core 22 feet—making, in quantity cut, 2¾ cubic yards, thus leaving a core of 22 feet diameter = 14 cubic yards) to be taken out by blasting, the same to be transported out under the machine, after it is run back, which I propose to rest for two hours, that the machine and engine, which is to be attached to the machine for its working and its locomotion, when perfected, may be examined, wiped, oiled, and any cutter or nut adjusted. During this two hours, the core will be blasted by means of cast-iron shells, so encased in wood as to fit exactly a portion of the ring; the same will be fired by electric battery.

"The space under the machine being 7 feet high and 10 wide, and a second track (narrow-gauge) laid between the machine track-gauge, for the transportation-cars, the cars (very low platform) will be run up and loaded. The 2¾ yards of dust to the foot, or 5½ yards for the 2-feet chip-cutting made by the machine (being transported out while the machine is in operation), but 14 yards to a foot, or 28 yards for the 2 feet, remain to be moved in the two hours = 10 car-loads. It will not be necessary to transport the whole (10) out in two hours, as the space between the machine and tracks will admit of their having two or three car-loads between the rails, which can be transported out while the machine is at work.

"One man will move 30 yards of stone in a day of ten hours with all ease, and on masonry work the average exceeds this. The moving and unloading of cars is comparatively small—the average time for loading, replacing the same with empty cars, will be 15 minutes, which can be done with all ease by eight men. Only six car-loads of stone to be moved in one foot = 12 car-loads in 2 feet, and as the two car-loads, contents of the ring, and two car-loads between the machine and the rails, are transported in the two hours, while the machine is at work, but eight car-loads remain to be moved in the two hours that the machine is idle, while the whole tunnel excavation will advance 2 feet on one face in four hours = 12 feet in 24 hours, and with two machines, one at each end, at the same rate, will progress 24 feet per day—thus completing the entire excavation of the whole tunnel in 1005 days, and present a hammered faced surface upon each and every side." *

Various trials, in the early days of the Hoosac Tunnel, were made with this machine, the total distance cut by it amounting to about 10 feet; but it did not prove successful. A second machine, constructed at Hartford, and known as the "Talbot Tunneling Machine," also working on the principle of revolving cutters, and adapted to cut out a core 17 feet in diameter, was tried about this time (1853) near Harlem, New York, but proved a failure. A third machine was constructed in New York, adapted to cut a core of 8 feet. This one was taken in hand by Mr. Herman Haupt, during his contract at Hoosac Tunnel. Haupt & Company expended about $25,000† upon it, but it was never put in practical operation at the tunnel. A machine of this description was reported in 1857 (about the time Mr. Haupt tried the above one) to have cut a 6-foot hole in hard rock, in California, at the rate of 23 inches in one hour and forty-five minutes, or at the rate of 26 feet per day, with one machine. This type of machine has been about given up in America. T. Lindsley's patent (No. 55,514, June 12th, 1866) and R. C. M. Lovell's (No. 67,323, July 30th, 1867) are probably about the last. Mr. B. H. Latrobe well put the objection to them in his report of October 1st, 1862, to the Commissioners of the Hoosac Tunnel.‡

* Report of Hearing, etc., before Joint Special Committee of the Legislature of Massachusetts (1853), p. 17.

† Boston "Daily Bee" Extra. Remarks of H. Haupt, June 9th, 1857, p. 7.

‡ Massachusetts Legislative Reports. Senate, No. 93, 1863, p. 135.

"The novel and ingenious machinery for driving the tunnel, either by an annular groove, or a cylinder bore in the centre of the section, I could entertain no confidence in, from the first suggestion, as they require the machines to do too much and the powder too little of the work; thus contradicting the fundamental principles upon which all labor-saving machinery is formed."

There is a description in the "Builder," vol. xxix., p. 463, for June 17th, 1871, of a borer invented by Von Schmidt, of San Francisco. It is a large rotary borer of 8-feet diameter, but instead of the cutters used in former machines, twenty-four diamond drills, placed 1 foot apart, are put around the rim. It is a novel application of diamond boring, but does not seem to have met with success. In the centre of the wheel is an advance borer, and the idea is to load only the central hole. The Brunton machine, which appears to give good promise, will, if it succeeds, be the first machine of the circular-cutting type that has stood a practical test, and even it is not intended for use in hard rock with alternate blasting, but simply in soft chalk where it is expected to bore its way like an auger. It has not as yet had any extensive practical test in a large tunnel, though many successful trials with it have been reported. It has been hoped that it might be applied in the construction of the long-proposed Channel Tunnel, should the latter ever be constructed. (Good descriptions of the Brunton machine will be found in Zwick's "Neuere Tunnelbauten," p. 68, with cuts. Also there is a paper on "Brunton's Heading-Machine," by William Johnson, read before the Chesterfield and Derbyshire Institute of Engineers, October 2d, 1875, and published by Bemrose & Sons, 10 Paternoster Buildings, London. See also "Engineering," vol. vii., p. 355, May 28th, 1869.)

And now let us turn to the history of the percussion rock-drill, as we now know it, the machine that has revolutionized tunneling, and made possible the construction of the great tunnels of Mt. Cenis and Hoosac, and which speeded the St. Gothard and the Sutro tunnels successfully to their conclusion. Where did it originate? At the recent formal opening of the great *Rothschönberger Stollen*, at Freiberg, commenced in 1844 and finished in 1877 (see p. 350), it was said* by the orator at the opening celebration (April 12th, 1877), that the rock-drill was originally a Freiberg invention, and was there tried in the Rothschönberg adit, but unsuccessfully; and that finally, after its perfection in America, the rock-drill had returned to Freiberg, its birthplace, and had been used in the completion of the tunnel. This, though a pretty instance of poetical imagery applied to a dark subject, is, nevertheless, wholly erroneous. The drill referred to is Schumann's percussion-borer, the original model of which is preserved in the Academy at Freiberg, and out of which the Sachs drill subsequently grew. It was invented in 1854–'55, and Fig. 82 is an illustration of the drill taken from Ržiha. Ržiha falls into the same error† as to the origin of rock-drills, in his earlier work, assuming that the Germans first designed them, saying: "It was German mining, especially Saxon, which took the initiative step in the construction of boring-machines; and from them Schumann's drill, introduced in the *Rothschönberger Stollen* at Freiberg, in 1857, was developed."

Stapff says:‡ "Freiherr von Beust advocated experiments with a machine to be driven by compressed air, a model of which had already been built in the summer of 1855 by the inventor Schumann in Freiberg. The first machine tried in the spring of 1856 was automatic, and a later one was patented in Saxony, February 17th, 1857. Toward the close of 1857, they

* Paper by R. W. Raymond at the May meeting, 1877, at Wilkesbarre, of the American Institute of Mining Engineers (Transactions of the Institute, vol. vi.) Also "Engineering and Mining Journal," New York, vol. xxiv., p. 330, November 3d, 1877.

† "*Lehrbuch der Gesammten Tunnelbaukunst*" (1864), vol. i., p. 134.

‡ "*Ueber Gesteinbohrmaschinen*," p. 133.

were introduced in the Rothschönberger Stollen, near Freiberg, regular work being done with them in 1858." (Their use, however, was subsequently discontinued, and it was only the last few hundred metres of the tunnel in 1875–'76 that were driven by rock-drills under a contract taken by Mr. Adolf Mezger). Now, here the claim is distinctly made for the first initial at-

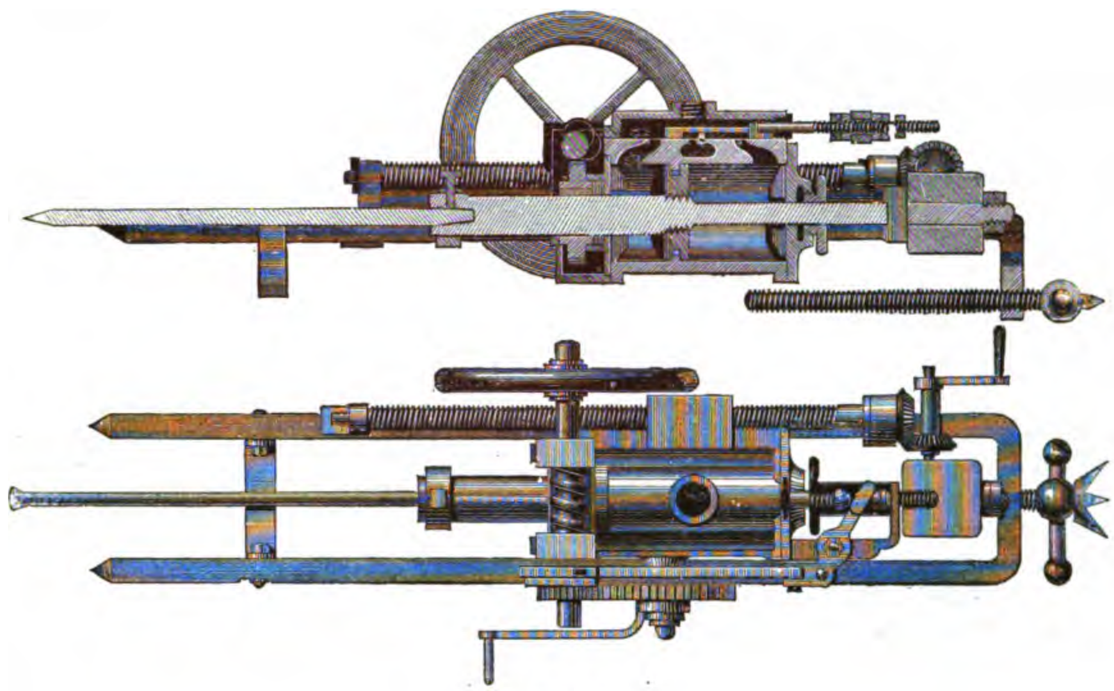


FIG. 82.
THE SCHUMANN DRILL.

tempts at constructing percussion rock-drills in Europe, as originating about 1854 to 1855 in Germany. In Ržiha's later work* (1876), he speaks of Cavé's rock-drill worked by compressed air; constructed in Paris in 1851. Stapff† gives cuts of this drill, and says it was patented in France, October 15th, 1851. This then would seem to be in reality the *first European percussion-drill.*

Fig. 83 is a sectional drawing of Cavé's drill taken from Stapff. The tool was rotated by hand by turning the handles *a* attached to the guiding-rods *o* of the drill. Drill was reversed by turning the valve by hand. Exhaust air or steam was led through a pipe *t* to the bottom of the drill-hole to keep it clean. Blow cushioned—exhaust steam being led off through ports at a distance from the cylinder-head. Drill designed to run with either steam or air, also "electric currents"—latter power not explained. According to Bande, in the "Berg u. Hütt. Zeitung," 1864, p. 148, "The machine works slowly and is difficult to handle." One would think so. It is further said that Cavé actually did run this drill with *compressed air* in 1851 (as noted above); also that rubber ("gutta-percha") conducting-pipe was used.

Now, imperfect as this machine was, it certainly is of great interest as being the *first* in Europe, and it is well to note how, from the very beginning, American drills have

* "*Eisenbahn- Unter- und Oberbau,*" vol. i., p. 35.

† Stapff, "*Ueber Gesteinbohrmaschinen,*" p. 531. See also on Cavé's drill, "*Bulletin de la Société d'Encouragement pour l'Industrie Minerale,*" 1863, 2d series, No. 132. Also the "*Berg und Huttenmännischen Zeitung,*" 1864, p. 147.

taken precedence over the European types. Two points about it, however, should be particularly noted: crude as it is, it nevertheless embodies the essential principles of direct action—*i. e.*, the drill is moved by the direct action of the steam, and not by an auxiliary en-

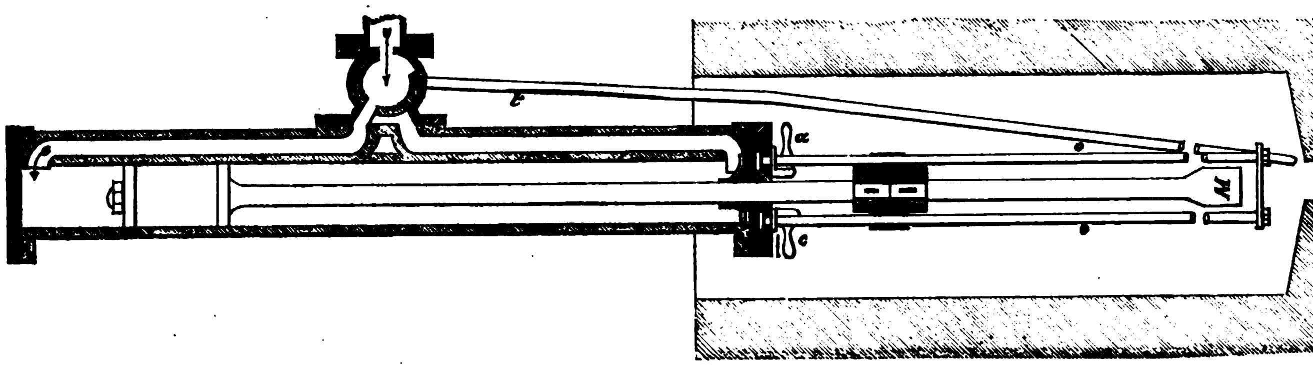


FIG. 83.
CAVÉ'S ROCK-DRILL.
(First European Rock-Drill. Patented, France, October 15th, 1851.)

gine, and, moreover, the drill is directly attached to the piston-head—*i. e.*, the "hollow piston" principle was not used. But it came far short of being a practical machine, since no motion was automatic. Indeed, it can hardly be called a drilling-machine, but rather a very crude apparatus for making an experiment. Now, Cavé's patent dates October 15th, 1851. Bartlett tried his first experiments in 1854—Schumann in 1854–'55.

Let us turn to the American record. The *first American percussion rock-drill* was invented by J. J. Couch, of Philadelphia, and his patent was taken out March 27th, 1849. Fig. 84 is an illustration of the method first proposed by the inventor for applying it (being a copy from an old print of the drill). Couch was aided in the construction of this drill by Joseph W. Fowle, more recently of Boston. Their experiments upon the construction of a machine rock-drill were carried on during 1848; in that year, Fowle built for Couch a working model, with which a number of holes were drilled in a block of granite.* In 1849, Couch and Fowle separated, and Fowle developed a drill of a distinct patent, which will be described farther on. In Couch's drill, the drill-bar passed directly through the piston of the engine, and was alternately caught, drawn back, and thrown like a lance against the rock. It was only used a short time in experimenting, but is of importance as being unquestionably THE FIRST PERCUSSION ROCK-DRILL EVER MADE which acted independently of gravity, and operated the valve of the engine which drove the drill.

Figs. 85 and 86 show the arrangement of Couch's first drill. A is a standing frame for supporting the operative parts of the machinery. B is a transverse and horizontal shaft, whose journals are sustained and revolved in boxes made in the upper parts of standards E, elevated above the bottom platform or board of the frame A. To this shaft B, the lower ends of two parallel bars, one of which is shown by *a*, are connected, these bars extending upward or above the shaft. Each of these bars has a clamp-screw *c* applied to it, and made to operate in such a manner as to enable a person to place the bar at any desirable inclination to the horizon, and to there confine it by clamping it to a quadratic arc F′ fastened to the frame A. This mechanism was intended for giving the drill the variously inclined, horizontal, or vertical positions required, and the ropes *p p′*, connected with the windlass *r′*, were used in raising or lowering it—two struts, one shown by Q′, being used to hold it in place when adjusted. It was, in fact, a primitive carriage. In connection with the parallel bars, of

* House, No. 375, p. 74 (Massachusetts Legislative Reports, 1866).

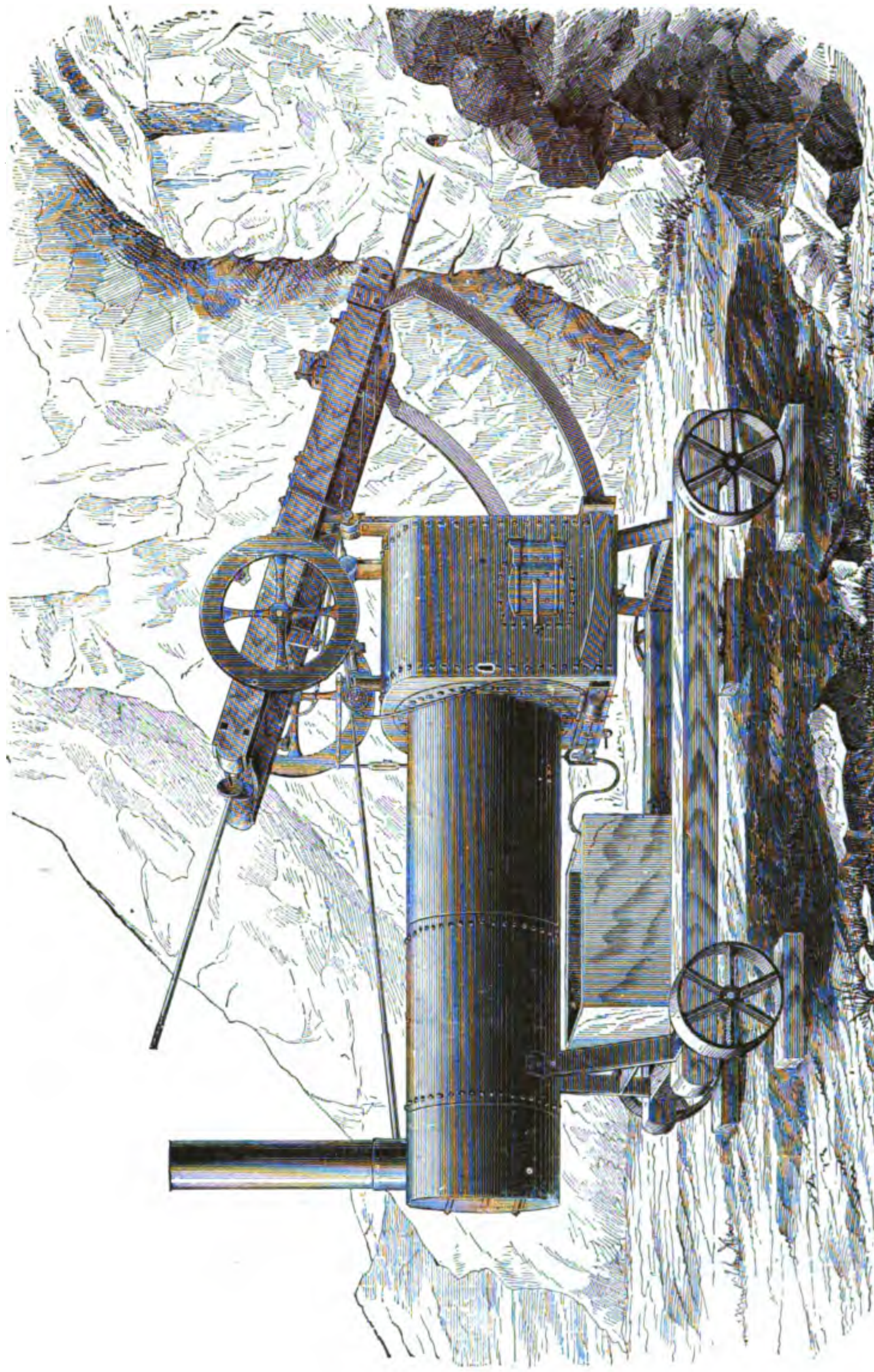


FIG. 84.

COUCH'S ROCK-DRILLING MACHINE.

The first Percussion Rock-Drill ever made Patented, United States, March 27th, 1849. (Copied from an old print.)

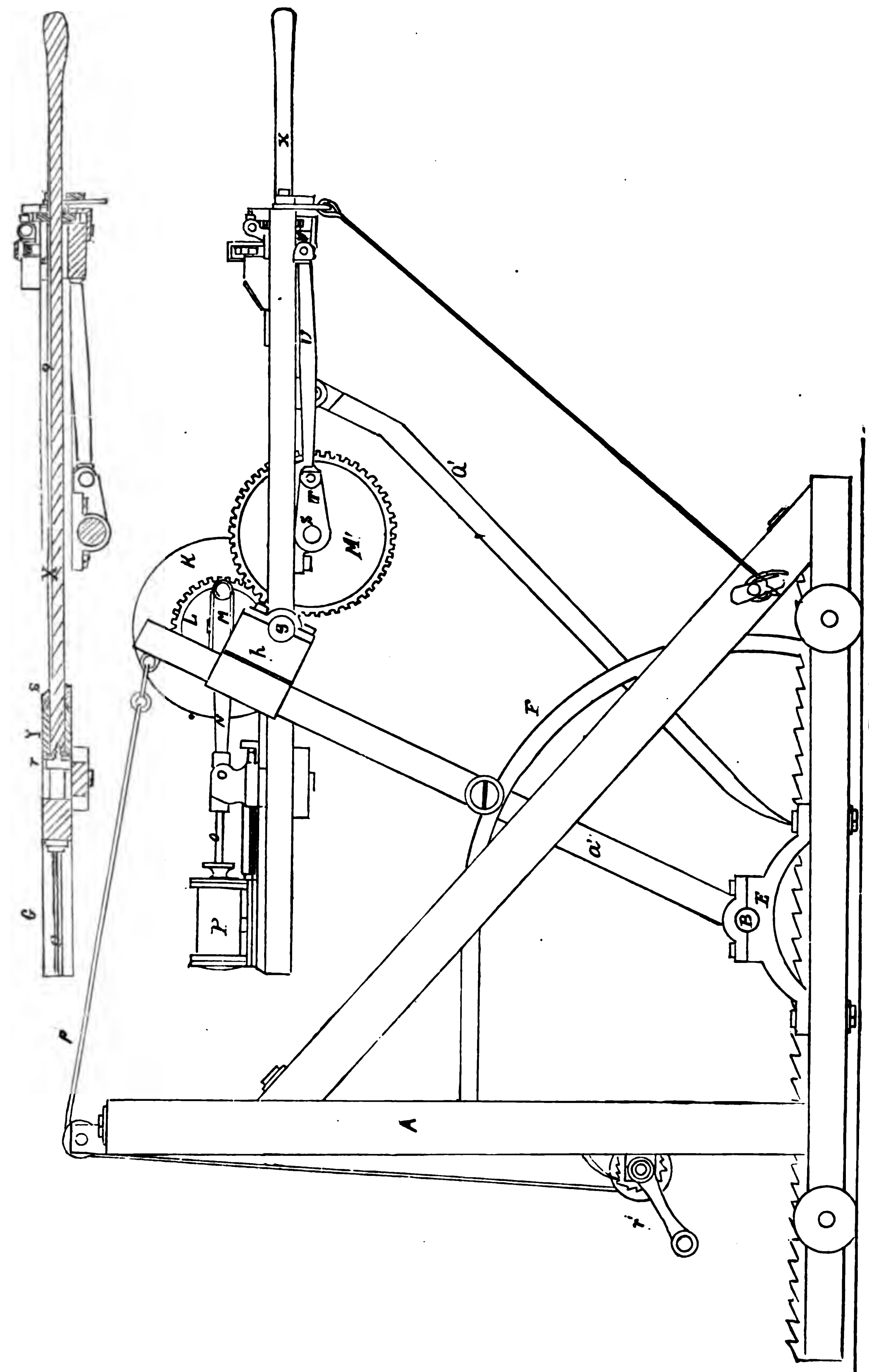


Fig. 85.

ELEVATION OF COUCH'S FIRST ROCK-DRILL.

Patented March 27th, 1849. (Exact copy, same size and lettering of drawings accompanying patent.)

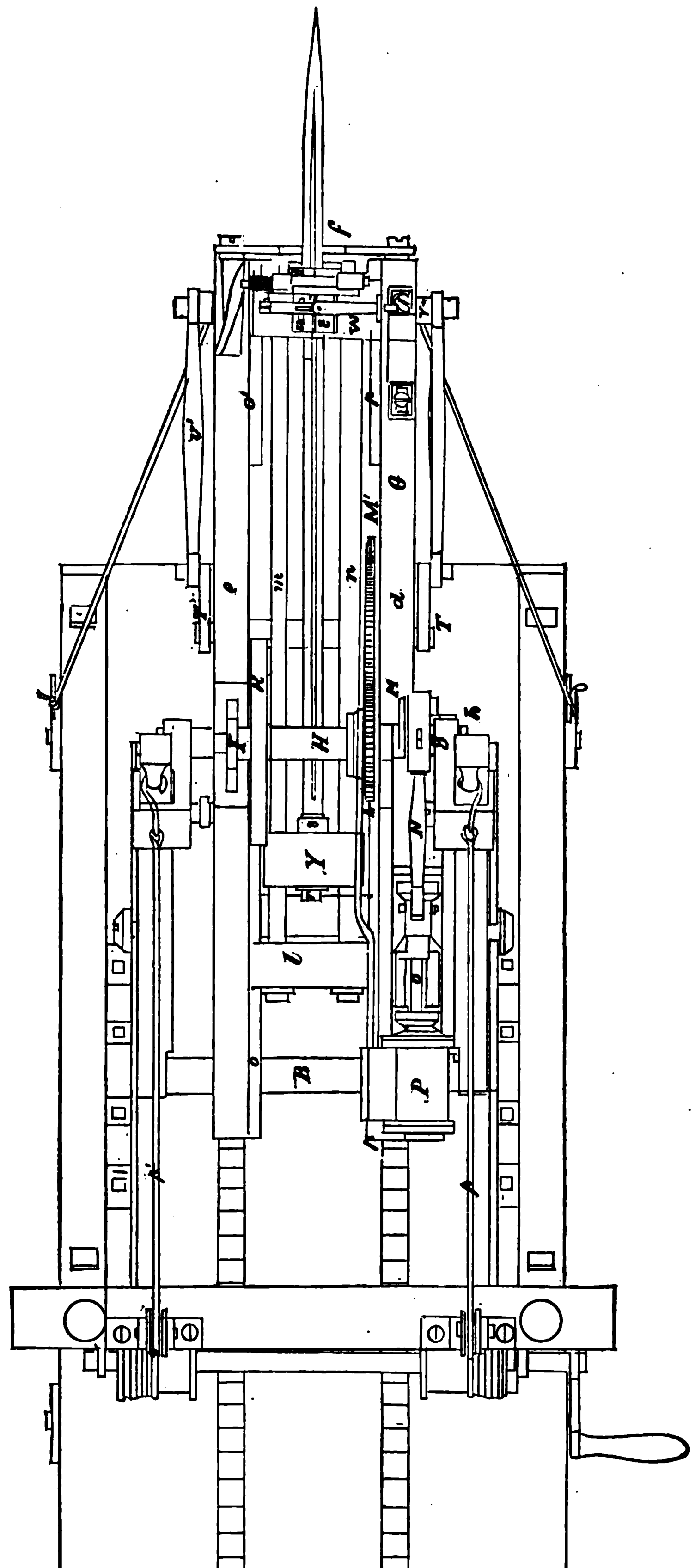


FIG. 86.
PLAN OF COUCH'S FIRST ROCK-DRILL.
Patented March 27th, 1849. (Exact copy, same size and lettering of drawings accompanying patent.)

which one a is shown, there is also a supporting and directing frame G, holding the drill-slide and the drill—this frame being composed of two parallel bars d e, connected with one or more cross-bars f, and arranged between the bars a, etc., above noted. Each of the frame-bars or pieces d e has a journal g projecting perpendicularly from its outer side and resting in a box h, so adapted to the adjacent bars a and its opposite fellow as to slide up and down upon the same. H is a driving shaft arranged across and above the frame G, and having its journals supported by bearings or standards I I, fastened to the frame. This shaft H has a fly-wheel K, a gear-wheel L, and a crank M, fixed to it as seen in the drawings, the said crank being jointed to the connecting-rod N of the piston O of a steam-cylinder P, fixed upon the rear part of the frame G, and having a suitable valve-chest and valves, and made to receive its steam by means of a flexible tube or other suitable contrivance, with a steam-generator arranged in some convenient position near the said cylinder.

The cog-wheel L engages with a gear-wheel M′ fixed on a crank-shaft S, this shaft being placed directly underneath the frame G. Two cranks T T′ are attached respectively to the two ends of the shaft S′ and have connecting rods U U′ extending from them, each of the said rods being jointed to one of two ears or projections V V′ which extend from the head k of a slide-frame W, which is composed of two heads or blocks Y l and two long connecting bars m n. The rotations of the crank-shaft S′ produced by the steam-engine impart to the sliding-frame W a reciprocating, rectilinear motion, the said frame being supported by and made to slide upon four ways or slides o' o' p p, two of which are affixed to each of the main bars of the frame G. X denotes the drill or its shank; it has a groove g cut in it, and extending nearly from end to end of the drill. The upper or end nearest the steam-cylinder passes through and revolves in a cross-head Y, which slides freely upon the two parallel bars m n of the frame W. Collars r s' are fixed on the drill-rod on opposite sides of the head Y, these collars being for the purpose of confining the drill-rod to the cross-head; the drill-rod is further supported in bearings t u, inserted in the cross-head k of the frame W.

It is not necessary here and it would be tedious to go into a detailed description of the griper-box used by Mr. Couch for catching and holding the drill on the back-stroke of the frame W, it consisting, in general, of a spring and lever arrangement held on the frame. This was so geared that when the drill struck against the rock, the shock or percussion of the blow could not injuriously affect the machinery. The drill, in fact, on the forward stroke of the frame was entirely disengaged from it, and was thrown by momentum alone against the rock. There was also an arrangement for rotating the drill by a ratchet-wheel catching into the groove cut in the drill itself; the novel feature of which was that the drill was arranged so as to pass freely through the centre of the ratchet-wheel. The wheel had a stud or projection which entered the groove of the drill; this stud served to connect the wheel with the drill.

This was Couch's first drill. In 1852 (November 23d), Couch took out a patent for another drill, in which he still adhered to the hollow-piston principle. Figs. 87(a) and 87(b) illustrate it. (a) is an elevation of the drill, and (b) a vertical longitudinal section. A is a steam-boiler, B the drill-cylinder with a piston c, the rod of which D extends out on either side of the cylinder. The whole length of the piston is made about double the length of the steam-cylinder. The piston is made hollow so as to receive the drill-rod E, and permit the rod to slide freely through it. F and G are the slides for the piston-head. Between them is the cross-head I of the piston. In this cross-head is arranged a griper-box for catching the drill on the back-stroke. R is a connecting-rod extending from an arm S′ to a crank-pin T of the fly-wheel U; O is the steam-pipe.

The machine was mounted on a circular disc X, which disc was secured to another permanent disc Y by means of bolts i i. The disc X had a trunnion g which extended into the

disc Y. When the bolts i were loose, the machine could be turned to any inclination, but when tight the machine was held in the desired position; steam was admitted into a circular groove $z z$, and thence conducted to the steam-chest, and the exhaust steam passed through an opening p in the trunnion g. This arrangement was designed to avoid flexible pipe. The valve-gear is not described in this patent.

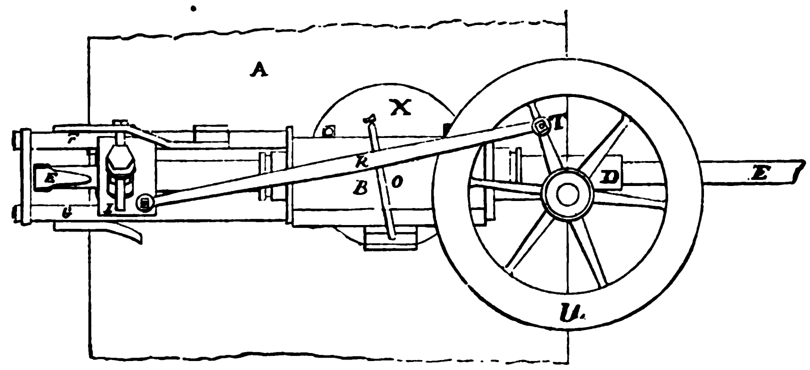


FIG. 87(*a*).
Plan.

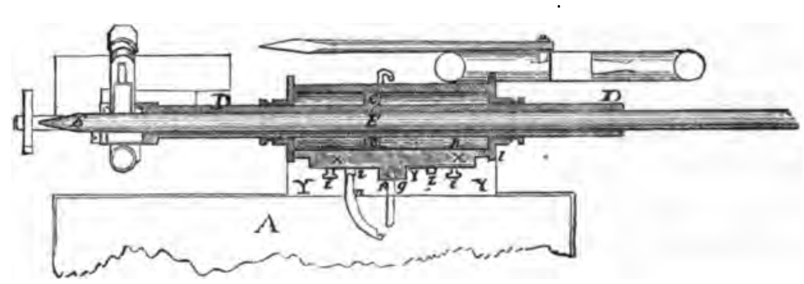


FIG. 87(*b*).
Section.

COUCH'S SECOND ROCK-DRILL.
Patented November 23d, 1852.

The idea of a hollow piston was a favorite one among many of the early experimenters on rock-drills in America. Though in the patents subsequent to Couch's the idea of throwing the drill was not followed, still a hollow piston, as claimed in his patent, was used in holding the drill, instead of the drill being, as we now see it in the general type of drills, fastened to the end of the piston or to a prolongation of it by a clutch, or, as it is commonly called, a "chuck." Mr. Herman Haupt claims* that the hollow piston-rod of the Couch patent was also separately invented by Stuart Gwynn, and applied in the course of the early experiments made by Mr. Haupt, in the construction of rock-drills, during his contract at the Hoosac Tunnel (1856–'61). It is said† that Gwynn first arranged in his mind the principles of his drill in 1850; his first drawings were made in 1851, and a model was constructed in 1852, but it was not until 1858 that Messrs. Gwynn and Haupt compared ideas and constructed jointly a drill which Mr. Haupt proposed using in the tunnel. It is said to have drilled, on trial, at the rate of five eighths of an inch per minute in the hardest Rockport granite.

The sudden termination of Mr. Haupt's Hoosac contract in 1861 (see p. 318) put a stop to these experiments for awhile. In 1864, Mr. Gwynn took out a patent for a hollow piston-drill of the Couch type; and in 1865, Mr. Haupt took out two successive ones, the later being

* House, No. 4, p. 14 (Massachusetts Legislative Reports, 1866).
† Claim made in Pneumatic Drill Company's Pamphlet, Boston, 1865.

for the drill he exhibited at the Paris Exposition of 1867. A pamphlet description of it was published by Mr. Haupt in 1867.* Its distinctive feature was claimed to be a momentum-feed.

Prior to this time, however, Harsen had taken out a patent in 1861 for another hollow piston-drill. This drill was tried at the Hoosac Tunnel,† under the direction of the State Commissioners, in April and May of 1865, at the central shaft, with steam as a motive power, but it eventually proved a failure. The main difficulty was with the cams and collars for seizing the drill-bar. In fact, it is to the Hoosac Tunnel that we owe the development of rock-drilling in America. Experiments were carried on by the Massachusetts State Commissioners after the tunnel passed into the hands of the State in 1862. They were supported by Mr. J. W. Brooks, Chairman of the Commission, but, as noted above, they were chiefly carried on under the direction and supervision of Mr. Thomas Doane, then Chief Engineer of the tunnel. The Commissioners (Messrs. Brooks, Felton, and Holmes), in their report for 1864,‡ say: "We have in hand three different plans of drilling-machines, two of which look very promising, and the third, though looking less so, has done some drilling with satisfactory rapidity." In their report for 1865,§ the Commissioners state that on December 16th, 1865, at a trial made in the Putnam machine-shop at Fitchburg, with the drills under construction, on a piece of rock taken from the tunnel, the average result of six holes was as follows:

Time consumed in drilling	34½ min.
Number of inches drilled	113¾
Average number of inches drilled per minute	3·3
Total time consumed	56⅝ min.
Average number of inches drilled per minute, including the time required to change the drills and set the machine to the different holes	2·01 min.

The holes being one and three quarter inches diameter. The Brooks, Gates & Burleigh machine, patented March 6th, 1866, was tried in June of that year at the East Heading. It

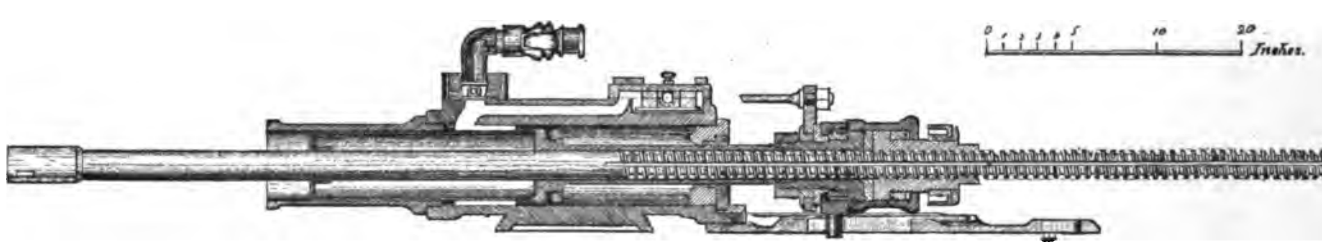


FIG. 88.

BROOKS, GATES & BURLEIGH DRILL.

was of the Couch type to the extent of having a hollow piston, but the tool, instead of being thrown, as in the Couch drill, was secured to the piston-rod by means of a central screw, and driven as in the Fowle type hereafter explained. The drills were made up of some eighty parts each; they weighed 240 pounds, would run about 200 strokes to the minute, and cost about $400. About forty of these machines were used in 1866 at the Hoosac Tunnel, but they were found to be far too expensive, the breakages being so frequent that a sufficient supply

* "Tunneling by Machinery," by H. Haupt, 1867.

† House, No. 4, p. 36 (Massachusetts Legislative Reports, 1866). (See also p. 260 of this work.)

‡ House, No. 3, p. 9 (Massachusetts State Legislative Documents, January, 1865).

§ House, No. 4, p. 8 (Massachusetts State Legislative Documents, January, 1866).

of machines could not be kept on hand, and in November of 1866 they were superseded by the Burleigh drill, which kept its place throughout the construction of the tunnel. During the time that the Brooks, Gates & Burleigh machines were used in 1866, a record was kept of the number of machines disabled and of the parts broken. According to the report* of the Joint Standing Legislative Committee for 1866, there were in all some 1084 sent out of the heading for repairs from July 21st to November 30th, a period of four and one third months, giving an average of 250 machines broken per month; or, counting twenty-five working days to the month, an average of ten machines sent out for repairs daily. No wonder these machines were found to be too expensive. The following table gives the principal parts that were broken during this period:

Cross-heads	62	Valve-stems	27
Cylinder-flanges	20	New packing	80
Coupling-nuts	30	Tappet-bars	151
Feed-springs	517	Screw-spindles	25
Feed-pawls	98	Union coupling-nuts	30
Ratchet-covers	200	Feed-nuts	47
Shields	20	Piston-heads	1

(See American Patent List, No. 52,960, for specific description of parts.)

This was the last effort made of any importance to perfect the Couch type of the hollow piston-rod. We now proceed to trace the history of the type which has become completely successful. Going back to Philadelphia in 1849, it will be remembered that Mr. Couch was assisted in the construction of his drill by J. W. Fowle. At this time, Mr. Fowle became impressed with the idea that the correct principle in constructing a rock-drill would be to impel the drill by the direct action of the steam or air on the piston, and not by means of an auxiliary engine. Moreover, he neither followed Couch's idea of throwing the drill like a lance, nor did he use a hollow piston for holding the drill.

Couch's patent was taken out on March 29th, 1849, and Fowle, on May 9th, 1849, filed a caveat for an improved rock-drilling machine, in which, in the words of the caveat, the distinctive claim was as follows:

"My steam drilling-machine is distinguished from all others which have heretofore been contrived in the following particulars: in the first place, the drilling-tool is attached directly to the cross-head of the engine, or, in fact, to an elongation in a direct line of the piston-rod, and is impelled or driven forward by the entire power of the steam-engine, which has never before been attained, as in all other machines about one half of the power is expended in driving the machinery which connects the engine with the drill. In the second place, the mechanical means for turning the drill as it comes back are much simpler and more effective than any other . . . . heretofore devised. Thirdly, as the whole increases in depth, the entire engine with its frame is accurately fed forward by means of the momentum of the cross-head. Fourthly, in a machine of this description, where the momentum of the piston is availed of in direct action, the piston would be in danger of being driven through the head of the cylinder; but this difficulty I have obviated by a peculiar arrangement of the machinery, which moves the rocker-shaft and shifts the valves. . . . In the last place, I make the cutting edge of the drill I use in the shape of an S, which has decided advantages over any other form now in use, but this I do not claim as my invention."

Fig. 89 shows Fowle's drill.

* Senate, No. 59, p. 35 (Massachusetts State Legislative Documents, February, 1868).

The rotation was effected as follows: A diagonal rod *k k* was fastened to the engine-frame. A ratchet-wheel was permanently fastened to the rear end of the drill-shaft *h h* and a pawl-holder *m m*, carrying a proper pawl, which engaged with the teeth of the ratchet-wheel.

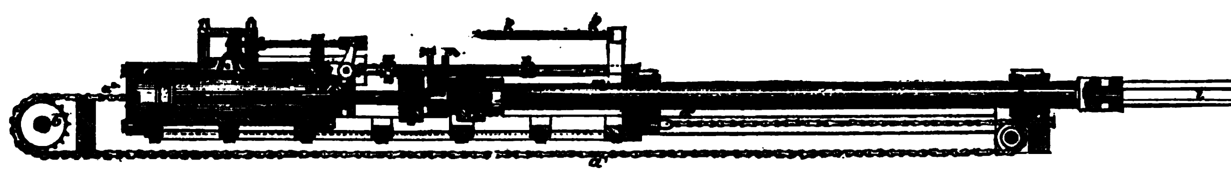


FIG. 89.
FOWLE'S FIRST ROCK-DRILL.
Caveat filed May 9th, 1849.

The feed was effected by means of an involved and cumbrous connection of the chain *a' a'* through the wheel *b'*, which again worked into an endless screw or worm on the end of a shaft parallel with the piston. This shaft was connected by an inclined plane, etc., with the cross-head of the engine.

This was Fowle's first idea of a drill as set forth in his caveat of May 9th, 1849.

In 1851 (March 11th), he took out the patent for his improved drill as shown in Figs. 90, 91, 92, 93.

Fig. 90 is a side elevation of the drill mounted on its support. Fig. 91 shows a plan of the drill alone. Fig. 92 is a longitudinal vertical section of the drill taken in the line A B of Fig. 91, and Fig. 93 is a transverse vertical section taken in the plane of the line C D, Fig. 91.

The following description of these figures is taken from Mr. Fowle's patent specification:

E E is a horizontal frame, having proper rails F F on which the supporting framework G G for the operating parts of the apparatus rests and moves along, the sliding or moving of the same being effected by the rack and pinion shown at H H in Fig. 90, or in any other of the well-known ways for producing such movements. On the rear part of the framework G G is the steam-boiler I I, the steam from which is conducted through the jointed pipe K K to the cylinder L of the engine. This cylinder is supported on the rectangular frame M M which is hung at its centre, so as to swing in the vertically sliding boxes on bearings N N which move up or down in the rectangular openings *o o*. These boxes are suspended at the ends of the cords P P and are raised or lowered by means of a windlass, to which the cord pays over guiding-pulleys R R. This windlass is provided with a ratchet-wheel and pawl at S, and the sliding-boxes may be confined in any desired position by means of the nuts and screws at T working with the confining buttons U U in a manner which will be readily seen from the figures. The frame M M is supported in the various diagonal positions into which it may be desired to bring it by the sustaining rods V V, which are conducted to its lower end on each side, and which at their other ends are bent so as to fit into the holes W, etc., in the horizontal and vertical metallic plates X X, Y Y.

a a is the drill-shaft having the drilling-tool *b* properly fastened to its outer end. Said drill-shaft is attached to or connected with the cross-head *c c* of the engine, so as to be nearly an elongation, as it were, of the piston-rod *d d*; thus the tool is driven forward by the entire power of the steam acting on the piston *e*, Fig. 92. The cross-head moves forward and back on the guides *f f*, *f f*, in the usual way, and the drill-shaft *a a* is arranged so as to turn in its bearings *g g* as it moves backward with the cross-head by the following arrangement:

A diagonal rod *h h* is fastened to the projection *i i* from the engine as shown in Figs. 90, 91, and 92. A ratchet-wheel *k*, Figs. 91, 92, and 93, is permanently fastened to the inner end of

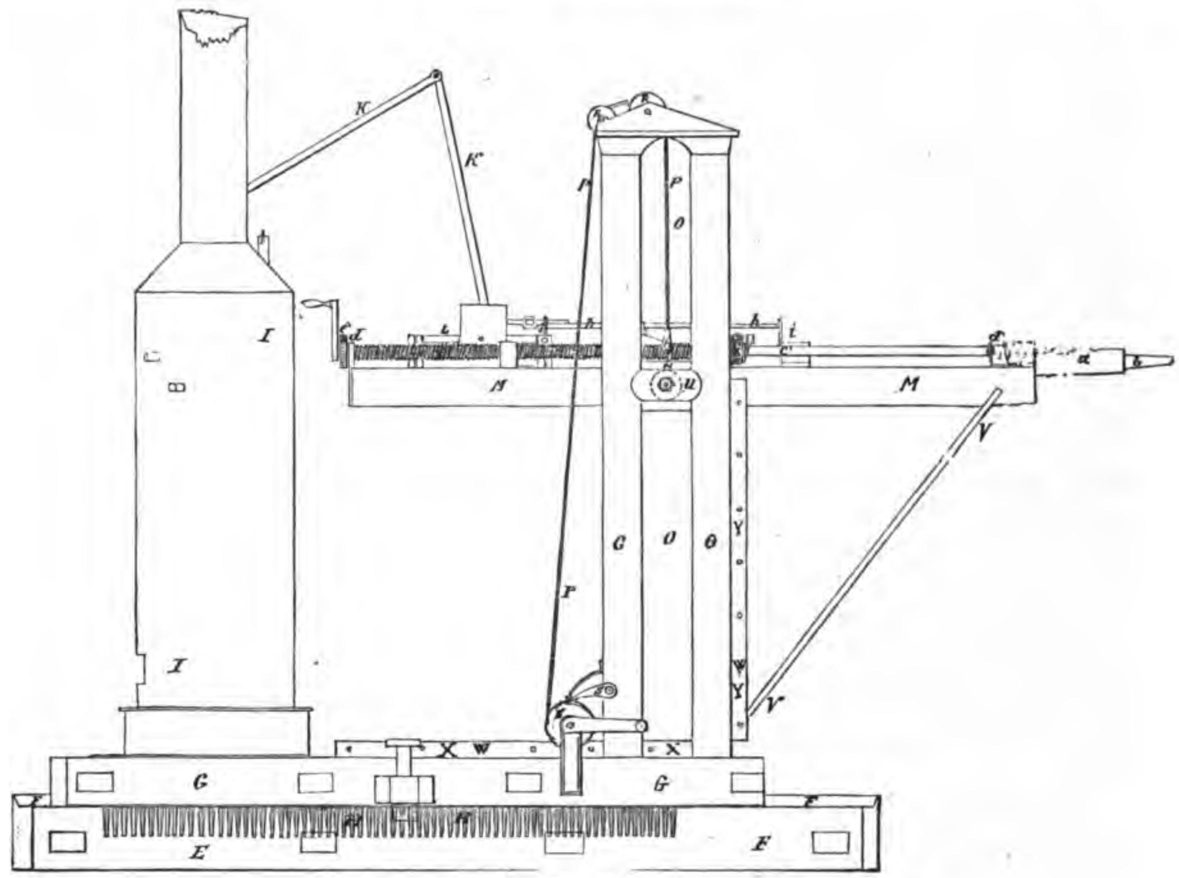


FIG. 90.
Elevation showing Drill and Carriage.

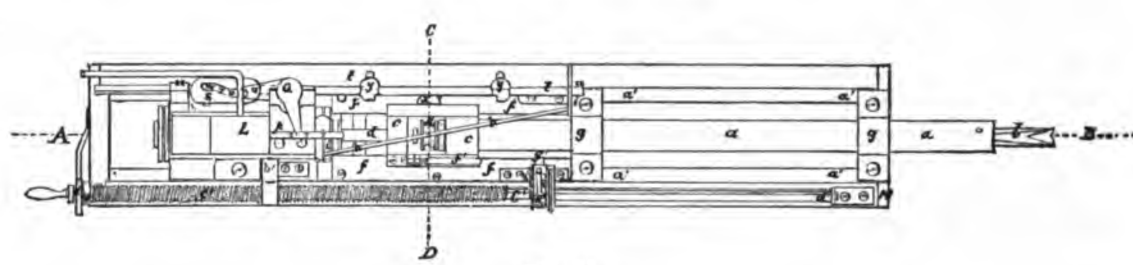


FIG. 91.
Plan.

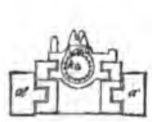


FIG. 93.

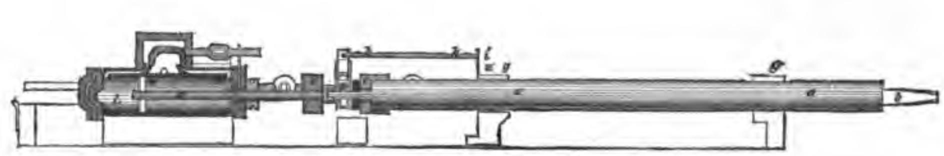


FIG. 92.
Section.

FOWLE'S ROCK-DRILL.

Patented March 11th, 1851.

the drill-shaft, and a pawl-holder *l* (having a pawl *m* (Fig. 93) which engages with the teeth of the ratchet-wheel) extends upward and is forked at its top so as to embrace the diagonal rod *h h*. As the drill-shaft moves forward, the pawl *m* moves over the teeth of the ratchet-wheel, and as the shaft moves backward the same pawl engages with the teeth and unerringly turns the tool, so that, in going forward again, it strikes in a different place.

The danger of driving the piston through the heads of the cylinder, by reason of using the direct action of the steam in driving the drill, is obviated by an arrangement for operating the rocker-shaft and shifting the valve of the engine just immediately preceding each stroke of the drill or before the piston fits close to either end of the cylinder. The rocker-shaft is a bell-crank having its arms nearly at right angles to each other, shown in Fig. 91, having a proper fulcrum at *o*. At the end of one of its arms, it is secured to the valve-rod *p*, and at the other it has a small pin or stud *g*, which fits into and is moved on or operated upon by the diagonal slot *r* in the plate S attached to the rear of the sliding-rod *t t*, which rod moves forward and back in proper guides at *u u* attached to the engines. From each end of this diagonal slot *r*, a horizontal slot, or one parallel to the axis of the cylinder L, extends toward the front and rear of the said cylinder, as shown at *v* and *w* in Fig. 91. The rod *t t* is moved forward and back by means of a stud *x* on the cross-head *c c*, which, as the cross-head moves forward and back, abuts against the adjustable tappets *y y* secured on the rod at proper points, so as to shift the valve at the proper time. Now, when the stone is soft, if the momentum which the piston has acquired would have a tendency to carry the cross-head farther along than the usual length of stroke, or than would be sufficient to open the valve to a proper degree, the horizontal slots at *v* and *w* (after the diagonal slot *r* has shifted the valve) only slide on the pin or stud *g* of the rocker, and have no further effect on the valve.

The next thing in course to be described is the mechanical arrangement for feeding the engine and drill-shaft forward as the tool enters the rock. The engine and its appendages are arranged so as to slide forward and back on the ways *a′ a′*, *a′ a′*, Figs. 91–93. A nut *b′* attached to the engine-frame fits on and is worked by the screw-shaft *c′ c′*, which is arranged so as to revolve intermittently at each stroke of the engine, and move the whole apparatus forward, a little each time. This shaft turns in its bearings *d′ d′*, attached to the swinging frame M M, and has a ratchet and pawl *e′* at its rear end (Figs. 90 and 91) to retain the gain which is made from time to time in the forward movement of the apparatus. A metallic inclined plane *f′* is attached to the side of the cross-head *c c*, and as said cross-head moves forward, this inclined plane presses against the end *g′* of the pawl-holder *h′*, and the pawl *i′* moved with this holder engages with the teeth of the ratchet-wheel *k′* (Figs. 90 and 91) fixed on the screw-shaft *c′ c′*, and thereby turns the shaft and effects the desired feeding motion. (The same end, it will be remembered, was produced in Fowle's caveat by means of a rag-wheel working in a chain attached to the two ends of the engine, this wheel being turned by the screw-shaft.)

No apology is offered for the amount of space which has been given above to the description of Fowle's invention, for we see that this was really the precursor of the rock-drill as we now know it. To Couch belongs the honor of designing the first percussion-drill as distinguished from a rotary borer, and to Fowle we owe the direct-action principle.

Mr. Fowle, in his testimony before the Massachusetts Legislative Committee on the Burleigh claim, in April, 1874, testified as to the original invention of his drill as follows:*

"My first idea of ever driving a rock-drill by direct action came about in this way: I was sitting in my office one day, after my business had failed, and happening to take up an

* House, No. 375, p. 79 (Massachusetts Legislative Reports, May, 1874).

old steam cylinder, I unconsciously put it in my mouth and blew the rod in and out, using it to drive in some tacks with which a few circulars were fastened to the wall. That was my first idea on the subject."

It should be noted in this connection that Fowle's caveat being filed in May, 1849, was only about two months after Couch's original patent, so that Fowle's invention, as well as Couch's, precedes, by about five years, not only all German work in this direction (as the earliest work on Schumann's patent is placed at 1854), but also Cavé's crude device by more than two years (see p. 194), which was not patented until October 15th, 1851.

It is interesting to note how completely this inventor (Fowle) comprehended the elements of the problem before him. He discarded light reciprocating parts, but instead of concentrating the weight in the piston-rod, as is now done, he attached to his cross-head a drill-bar (to which the tool was attached), which weighed over one hundred pounds. Having a drill-cylinder with light flanges, and fearing that he would break them by the piston striking the heads, and thus spoiling the cylinder, he secured the heads to each other by means of long rods passing from one to the other, and thus avoiding an attachment to the cylinder, and, as he reports, "I thus saved my cylinder." This principle has been incorporated into several modern drills. He used a flexible hose to conduct steam from the boiler to the machine. In 1850 or 1851, *he used compressed air* for driving his drill. He overcame the difficulty of making round holes with a machine-drill by making an **S** drill—a form which has since been used for the same purpose, though the **Z** and **+** bits are more commonly used because they are more easily sharpened. When the Italian and French commission came to this country to ascertain what they could find here that would be of service in the construction of the Mont Cenis Tunnel, they examined the models in the Patent Office, and finally adopted the Fowle type—*i. e.*, they attached the drill to the piston-rod in such a way as to drive it directly by the piston.

We also notice that the hollow piston-rod of the Couch type had its birth and entire life in this country. The only one patented abroad was by Haupt in England. (See English rock-drill patents, 1865, No. 981.) In the same list of patents, 1874, No. 2085 is a patent in which there is a hollow piston-rod. In this drill, the end-screw passes through the piston-rod and reciprocates with the piston, the tool being attached to the screw. The cylinder is stationary as in the Couch type, but the tool is driven directly as in the Fowle type. This drill is similar in principle to the Couch drill. All the principal foreign inventions were on the direct-action principle of the Fowle type, but most of them dispensed with the cross-head, and attached the tool directly to the piston-rod, the tool and piston being rotated together. (See English patents for 1858 and afterward.) Fowle had not the means to bring his drill into practical use, but had he done so, it is evident, from the ability which he possessed of overcoming difficulties, that machine-drilling in this country would have been advanced by several years. As it was, it lay in abeyance until taken up by Burleigh.

Seeing the poor success attained by the Brooks, Gates & Burleigh machine, Mr. Charles Burleigh abandoned the idea of constructing a machine on the Couch or hollow-piston principle, purchased the Fowle patent,* and incorporated it in the Burleigh drill.

Burleigh improved on Fowle in the details of the machine. He dispensed with the cross-head and intermediate drill-bar, attached the drill directly to the piston-rod, and rotated the tool by rotating the piston. The feed, rotation, and other improvements are described further on. He was apparently the first inventor in this country to improve upon the Fowle type. In his report for 1866, Mr. Doane, as Chief-Engineer of

* Evidence of Charles Burleigh before Hoosac Tunnel Committee, House, No. 375, p. 8, Massachusetts Legislative Documents, May, 1874.

the Hoosac Tunnel, speaks of* "an improvement upon the first machine (*i. e.*, the Brooks, Gates & Burleigh drill, see ante p.201),perhaps indeed a new machine, invented by a member of the Putnam Machine Company, Mr. C. Burleigh. It is made up of the same number of parts as the first machine, is inferior to the first in compactness, weighs 372 pounds, and is not practically automatic as yet. The two machines drill at about the same rate, but the second one is likely to prove much more durable than the first." . . . . "Of all the reciprocating machines brought to your notice, that of Mr. Burleigh seems to me most promising." In the report for 1867 of the Joint Standing Commission on the Hoosac Tunnel, of the Massachusetts Legislature,† occur the words, "the drill is a mechanical triumph, a success," and Alvah Crocker, acting as superintending commissioner of the tunnel for that year, in his report to the governor and council,‡ speaking of the drill, calls it "the best drill yet in use, at once a monument to the genius of Mr. Burleigh, the inventor, and a credit to Massachusetts." How well this early promise has been fulfilled is testified by the record of the Burleigh drill throughout the construction of the Hoosac, and by its subsequent adoption at Nesquehoning Tunnel (the second tunnel in the United States in which rock-drills were used); by its history at Hell-Gate and throughout the Western mining regions, and by its record, in 1875, at

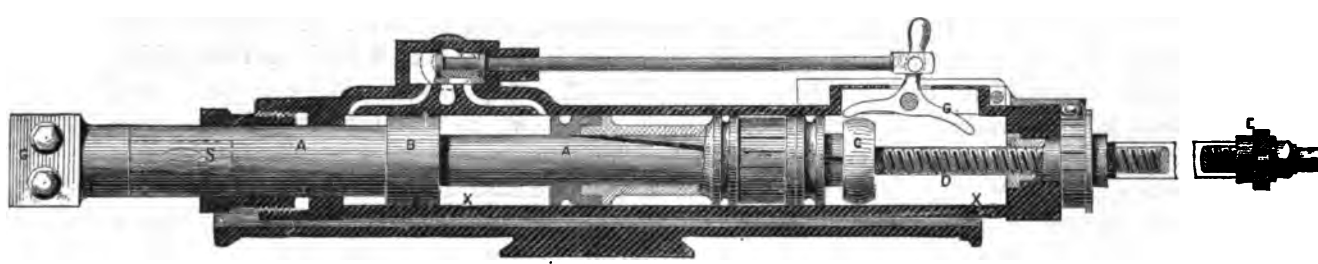


FIG. 94(*a*).
THE BURLEIGH DRILL.
Scale, $\frac{1}{16}$.

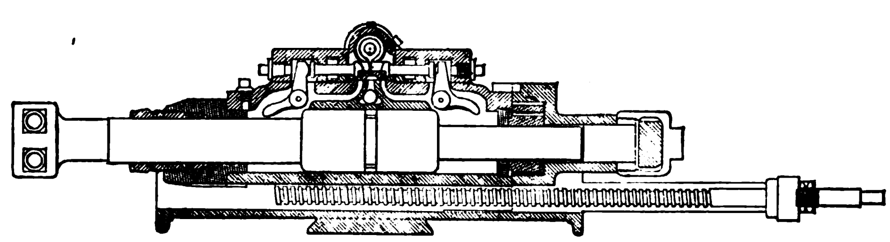


FIG. 94(*b*).
IMPROVED BURLEIGH ROCK-DRILL.
Second patent. Scale, $\frac{1}{16}$.

the Sutro Tunnel, where the rate of progress per month was raised to between three and four hundred lineal feet per month, a rate fully rivaling, and, in fact, as to the quantity of rock removed at the heading, surpassing that attained at the St. Gothard Tunnel, as the area driven was considerably larger. With regard to the date at which the Burleigh drill was started in the Hoosac Tunnel, the first drills there used were put in the heading October 31st, 1866.§

* Thomas Doane's Report for 1866, House, No. 30 (1867), p. 19.
† Senate, No. 102 (1868), p. 9.
‡ Senate, No. 20, p. 18 (Massachusetts Legislative Report, January, 1868).
§ Report of the evidence in the Burleigh Claims, Mass. Leg. Rep., House, No. 375 (May, 1874), pp. 20 and 82.

The early Burleigh drill (see American Patent List, No. 59,960) remained essentially unchanged until 1872. It had been urged, as an objection to the working of the drill, that the exposed tappet, Fig. 94(*a*), rendered it liable to breakage. This was obviated by placing the tappets inside (see second Burleigh patent, American Patent List, No. 162,258), making, as seen by Fig. 94(*b*), a small, compact, and powerful machine.

We now come to another important drill, whether it be considered historically in connection with the rise of machine-drilling in America, or, practically, in its improved form, as one of the leading drills of the present day. This is the Wood & Robinson drill. In point of actual date, it was, perhaps, the first practical American drill which was constructed on the direct-action Fowle type (Fig. 95).

The general plan of this drill appears to have been conceived by Professor Wood (who then held the chair of Civil Engineering in the University of Michigan) while on a visit to the iron mines on Lake Superior, in 1863, but it was not reduced to a practical form until 1866. In the latter part of 1865, he associated with him Mr. S. W. Robinson, a graduate of the University (now (1882) Professor of Mechanical Engineering in the Ohio State University), and

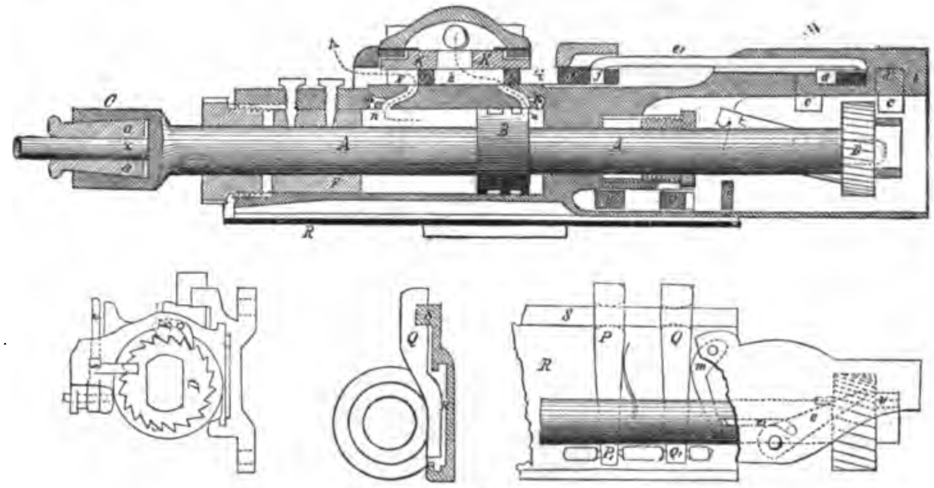


Fig. 95.
Scale $\frac{1}{10}$.

they proceeded together to reduce the invention to practice. A caveat was filed in March, 1866; a machine was completed and put into practical operation prior to August 16th, 1866 (see Ann Arbor "Courier and Visitant," August 16th and 23d, 1866), but the patent did not issue until November 26th, 1867 (see American Patent List, No. 71,329), one year after the date of the Burleigh patent. The fear that the Wood drill might involve an infringement of the Burleigh patent seems to have been the chief cause of its not having been fully tried by the commissioners at the Hoosac Tunnel, in competition with the latter; it was, however, tried by Dull, Gowan & Co., during their contract at Hoosac, in August, September, and October of 1867, and Mr. Benjamin H. Latrobe, Consulting Engineer, says in his report for that year: * "There is now lying in the shop at the east end a machine, invented by parties from Michigan, differing in several respects from the Burleigh drill, although claimed, as I am told, to conflict with patent rights of the latter. Of this part of the case, I know nothing as yet, but the machine has been reported to me as working with greater efficiency and small cost of repairs, on account of its fewer parts and simpler construction. It seems to have been introduced into the tunnel by

* Senate, No. 20, p. 31 (Massachusetts Legislative Documents, January, 1868).

the late contractors, and to have been disused on their retirement from the work; but for what reason I am unable to state, as its performance is said to have been exceedingly promising of improvements over previous machines." In the letter of Hon. Charles Hudson, one of the commissioners of the tunnel (bearing date January 1st, 1868), to the Governor of Massachusetts, he says:* "This drill, patented by a gentleman in Michigan, has the recommendation of great simplicity. The contractors speak of it in the highest terms. They say it contains only about half as many parts as the Fitchburg drill, that it requires less repairs and fewer hands to operate it, and will perform a third more work. But it is alleged that this patent infringes an old patent which is soon to expire, which has been bought up by Mr. Burleigh."

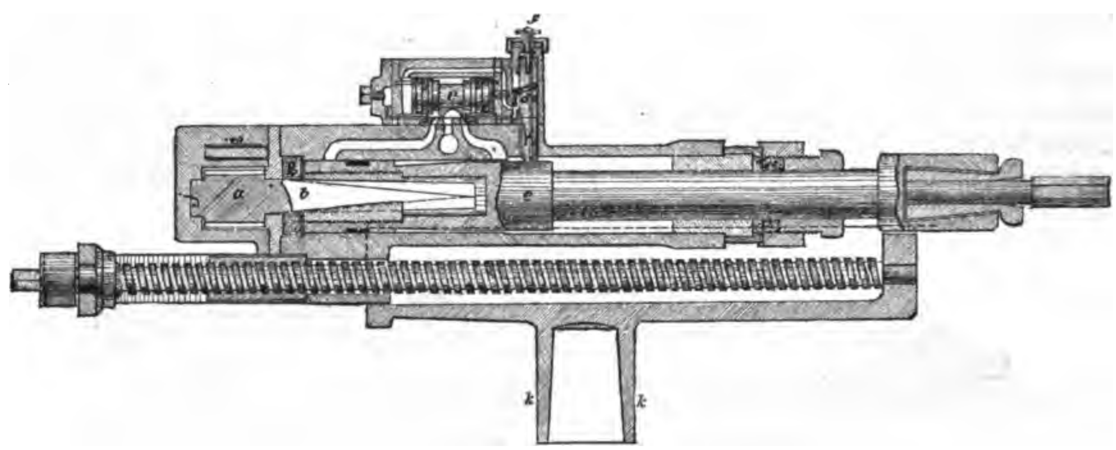


FIG. 96(*a*).
WOOD ROCK-DRILL.
Scale, ⅙.

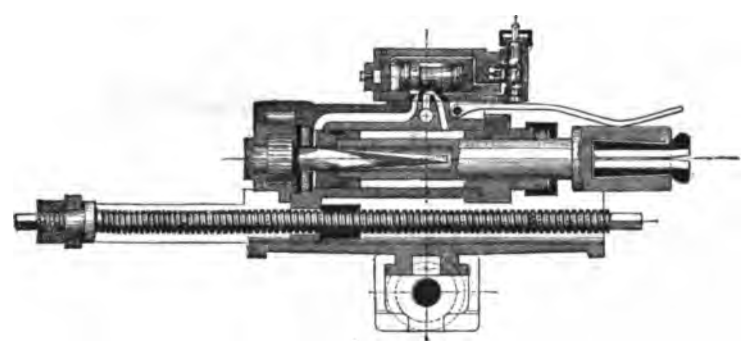


FIG. 96(*b*).
IMPROVED WOOD ROCK-DRILL.
Scale, $\frac{1}{16}$.

(The "old patent," referred to by Mr. Hudson, was the Fowle patent, which, it will be remembered, Mr. Burleigh purchased, owing to his own invention having also infringed the original direct-acting-piston claim of Fowle.) In his testimony before the Committee of the Legislature, in 1872,† Mr. Hudson further said (testifying as to the introduction of the Burleigh drill at Hoosac): "A contract was made with certain gentlemen (Dull, Gowan & Co.), and they came on and commenced work there. After they commenced work, a gentleman from Michigan (Ann Arbor), whose name I do not recollect, came on there with a drill that he had projected, and these contractors took that drill, and used it a day or two—*i. e.*, they experi-

* House, No. 359, p. 6 (Massachusetts Legislative Documents, May, 1868).
† House, No. 375, p. 14 (Massachusetts Legislative Documents, May, 1874).

mented with it a little, and were satisfied with its success. But we were satisfied that this drill was an entire infringement on Mr. Burleigh's patents, and that our obligations to Mr. Burleigh ought not to allow us to suffer the Michigan drill to be used by the contractors. It was there a few days, and was used to their satisfaction, I believe, and it operated very well; but we were all satisfied, and Mr. Crocker very particularly urged, that as Mr. Burleigh had allowed us to use his drill, and there was this understanding between us, we were under obligations to exclude the Michigan drill. This was done peaceably and quietly, but that was the sentiment which prevailed."

Similar testimony was given by Mr. J. M. Shute, who was also one of the State commissioners.*

The Wood drill—see pp. 210 and 242—was an improvement upon the Wood & Robinson drill (see American Patent No. 138,777), and the improved Wood drill—Fig. 96 (*b*)—is classed in common with the Burleigh, Rand, Union, and Waring drills, in the rank of the drills prominently before the American mining market. The latter three are later drills, and their characteristics will be found described in the following table of American drills; the Wood drill has been touched on at length as being closely identified with the history of the rise of machine-drilling in this country, and especially as connected with the history of the Hoosac Tunnel.

And now that we have traced up the rise and history of machine-drilling in the land of its birth, let us return to Europe, and take there also a view of the introduction of machine-drilling, before entering on the practical discussion of the construction of the various machines.

We have seen that Cavé patented a percussion-drill, to work with compressed air, in France, in 1851.

Bartlett came next, in England, in 1854, with his invention of a drill proposed for Mont Cenis; it was patented in England, August 23d, 1855, the patent in Sardinia being taken out June 30th, 1855. The first trial of this drill was made at Brighton, in June, 1854. In March and April, it was tried with success before an Italian commission, at St. Pierre d'Arena, compressed air being used to run it. Following Bartlett's machine in date came Schumann's, which, as we have seen (p. 193), was not practically tried until 1856, though it was invented during 1854–5, and the first model made in 1855. Then came Sommeiller's first machine, in 1857, patented in June, and Schwarzkopf's drill, invented in the same year, but not patented until November 5th, 1858. Finally, March, 1861, Sommeiller had so perfected his drill that it was formally adopted at the Mont Cenis Tunnel. From this date on, in Europe as in America, there were many patents taken out; prominently among them we may note those of Low, 1863 and 1865; De la Haye, 1863; Sachs, 1863; Bergstrom, 1865; Doering, 1866, 1867 and 1868; De la Roche-Tolay, 1867; Dubois-François, 1868; Osterkamp, 1869; McKean, 1872; Brydon, Davidson and Warrington, 1872; Ferroux, 1873; Azzolino dell'Acqua, 1873; Darlington, 1873. Of these, the only ones that have survived the practical test of usage seem to be the Ferroux (which resembles Sommeiller's in having an independent engine to operate the valve and rotation, and Low's in having the feed induced by the compressed air in another cylinder), the McKean (an outgrowth of Haupt's American drill), the Dubois-François, the Darlington, and also, perhaps, the Sachs (an outgrowth of Schumann's drill). (See European patent lists following for particular descriptions of these drills; some will be found under the English and some under the following list.)

Sommeiller did for Europe what Burleigh afterward did for America: he practically applied what before had been experimentally tried; his ultimate success, however, is so far behind Burleigh's in that, while in practice we see the Burleigh drill in as great favor as in the year of its invention, Sommeiller's drill is relegated to the past as one of the great

* See "Rejected Papers" (Massachusetts Legislative Documents, 1866).

inventions which served a purpose—but a single purpose only. Still, in Sommeiller we must recognize the man who undoubtedly first demonstrated to the world, in 1861, that the machine-drills invented twelve years before, by Fowle, in the United States, could and would be the essential feature in accomplishing one of the great advances of the nineteenth century; for Sommeiller's drill, past and done as it now is, took precedence by some five years of Burleigh's in America (1866), and by some seven, eleven, and twelve years the three first European drills in general use, the Dubois-François, McKean, and Ferroux.

Characteristic Features of Percussion Rock-Drilling Machines.

Now, before we turn to our lists and particular descriptions of rock-drills, it may be well to have clearly in mind the essential attributes of a good rock-drill—one that is not only a perfect machine, but that will stand the wear and tear of the tremendously hard usage to which these machines are subjected. As to the comparative excellencies or characteristics of the different drills reported, it would not be wise to attempt to discuss them, or to lay down any rule or dogma as to which may be the "best drill." The experience of the author has been that any such assertions are based on such variable ground that what may be the best drill to-day will be superseded to-morrow by a new point that has been made in another. Some drills may be superior in certain points and inferior in others. Also, a drill that will do work satisfactorily under certain conditions may be worthless in other places. The results of competitive trials of a few hours' or a few days' duration are frequently cited as establishing the efficiency of one drill over another. These statements should invariably be received with the greatest caution, and, as a rule, however carefully and honestly such trials may be made, their results are very rarely worth attention. There is no fair test of a drill that does not involve its being put to hard regular work, and its work averaged with that of other drills for some time in the same material and under the same circumstances. The fact is, that the market competition in these machines has grown to be so great that there is not so great a difference between the different makes of drills as the manufacturers and agents of each particular drill company are apt to claim. They all have to come up to a certain standard, and the poorer ones drop out of the market. It is not this patent or the other patent, this little improvement on a valve, or that change, say, in a gearing, that will settle the question; the great step was in the original transition from hand to machine labor. The latter having been once practically demonstrated to be possible, the application naturally became widespread. Since that time, in the various practical tests they have undergone, there has been a sort of process of improvement by *natural selection* going on through many types, and we probably have by this time reached nearly the point of ultimate efficiency to be attained in this department. What the next grand departure of the future may be, who can say?

André, in his admirable discussion of rock-drills,* has well put the characteristics to be fulfilled by a good drill. These are as follows:

1. A machine rock-drill should be simple in construction and strong in every part.
2. It should consist of few parts, and especially of few moving parts.†

* André on Coal Mining, p. 148.

† Still, a rock-drill may be made of too few parts. It is very common with young inventors, as soon as they experience the severe wear and tear of the machine, to seek to make it of as few parts as possible; but when the machine finally comes to the point of "repairs" (and the best will reach that point sooner or later), it may be found that one of the most essential qualifications of a good rock-drill has been overlooked. While we agree with Mr. André that the parts should be as few as practicable, we know by experience that this principle may be carried too far, and that it is even more important that every part should be easily renewed—*i. e.*, that Mr. André's twelfth condition should be complied with. The life of this class of machines lies in their ability to be renewed piece by piece. When a drill is thus constructed, and one is using it who is thoroughly acquainted with it, and when a sufficient number of duplicate parts are at hand, it can often be kept running month after month without dismounting, despite breakages and wear.

3. It should be as light in weight as can be made consistent with the first condition.*
4. It should occupy but little space.
5. The striking part should be of relatively great weight, and should strike the rock directly.
6. No other part than the piston should be exposed to violent shocks.
7. The piston should be capable of working with a variable length of stroke.
8. The sudden removal of the resistance should not be liable to cause injury to any part.
9. The rotary motion of the drill should take place automatically.
10. The feed, if automatic, should be regulated by the advance of the piston as the cutting advances.
11. The machine should be capable of working with a moderate degree of pressure.†
12. It should be capable of being readily taken to pieces.

External gear in a rock-drill is especially to be avoided. In regard to an automatic feed, it would seem that a majority of those who use drills prefer a hand feed on account of the increased simplicity of the machine which results from abandoning the automatic device, but a few insist upon using an automatic feed, regardless of cost of the repairs which it entails.

The fifth condition above is one of great mechanical importance. In comparing the relative merits of rock-drills, the number of strokes a minute which any one is capable of making is often insisted on as the basis of a comparison of efficiency, that one being considered the most efficient which is capable of making the greatest number of strokes. This notion is an altogether erroneous and a pernicious one, inasmuch as it tends to perpetuate and increase a somewhat serious defect. Too high a piston speed is undesirable in a percussion rock-drill, mainly for two reasons. First, the resistance to be overcome is great. The operation of boring with such machines consists in fracturing the rock by a succession of heavy blows, and it is evident that the heavier the blow, within the limits of the endurance of the tool, the greater will be the effect.‡ To obtain a heavy blow, there must be a large moving mass. But an augmentation of the mass is, other things being equal, incompatible with an increase of velocity. Hence it becomes desirable, as far as the third condition will allow, to renounce velocity in favor of mass—*i. e.*, as much as practicable of the weight of the machine should be concentrated in the piston and piston-rod. With such a disposition of the parts, the work of a drill must necessarily be more effective.

Second, when the moving mass is light and the velocity high, not only is the great resultant vibration absorbent of force, but very destructive to the joints and conducive to fracture in the moving parts; and, moreover, the inevitable wear and tear are thereby im-

* The weight depends upon circumstances. If the machines are mounted on frames or carriages, and moved on wheels, we would say make the machines *very* heavy; but if they are to be portable, and frequently dismounted in moving them, then the condition holds good.

† There are two sides to the question of pressure. If the drills do good execution at a low pressure, they must be correspondingly large and heavy, thus violating condition 3. It is said that drills in the Western States are generally run at from sixty to ninety pounds of air. Such a pressure in the early days of Hoosac would have torn every thing to pieces, but we have learned now to make them stand, and miners insist on having lighter drills, thus necessitating more driving power. But it is decidedly questionable whether the pressure, when economical, steady work is considered, should exceed sixty pounds; but there may of course be exceptions.

Practically, the question is not one purely of high or low pressure, nor one of large or small drills, but of economy in work and of rate of progress attained. When time is the chief element, great cost in expenditure may result in ultimately greater economy in time; when economy is to be rigidly observed, it may be promoted at the expense of time.

‡ Theoretically, the stroke should be very short, so as to divide the work of the motor into a very great number of blows, and so pick the rock to pieces. A blow hard enough to break and smash the steel may indent the rock; but divide this blow into many, and we drill a hole. But the stroke may be too short. There must be a certain clearance, and the shorter the stroke the greater the percentage of loss of steam in filling the cylinder. Also, the drill must churn up the *débris* in the hole so that the water will wash it out; but if the stroke is too short, it will only clog. Hence we have a paradox—to drill hard rock requires a harder blow than to drill soft rock, but to clear the hole requires a longer stroke; so that a drill with 3½-inch stroke drills hard rock best, but for soft rock it should be six or seven inches. A long, heavy stroke on hard rock jars the machine too much.

mensely increased, so that the tendency to derangement is greatly augmented by the adoption of high velocities.

Also in condition (5) the clause requiring the striking mass to impinge directly upon the rock, is one that has been violated in the hammer-machines, etc. Though this type has now been probably permanently relegated to the shades of the past, it may be desirable to investigate the direct loss of power in their use.* Let M denote the mass of the striking part, M′ that of the body interposed—*i.e.*, of the tool struck; V the velocity of the striking mass, and V_1 the common velocity of the two bodies after impact. Then we have

$$M\,V = (M' + M)\,V_1;\ \text{whence } V_1 = \frac{M}{M' + M}\,V;$$

hence the effect of the blow will be proportional to

$$(M' + M)\,V_1^2 = \frac{M}{M' + M} \times M\,V^2.$$

The work developed by the motor is $\frac{1}{2}\,M\,V^2$; and thus it is evident that the effective work done upon the rock will be proportional to the fraction $\frac{M}{M' + M}$—*i. e.*, it increases as M increases and as M′ diminishes. To take an example: Suppose a machine, the piston and piston-rod of which weigh 24 lbs., to which a tool is fixed weighing 8 lbs., the velocity of the piston being 5 feet a second. In this case, $M = \frac{32}{32\cdot 2}$, $M' = 0$, and $V = 5$; and the work developed will consequently be $\frac{1}{2}\left(\frac{32 \times 5^2}{32\cdot 2}\right) = 12\cdot 4$ units of work. Suppose, now, the tool to be detached, and the piston to strike the head of the tool. In such a case, $M = \frac{24}{32\cdot 2}$, $M' = \frac{8}{32\cdot 2}$, and $V = 5$ as before. The work done upon the rock will be

$$\frac{1}{2}\left(\frac{24 + 5^2}{32\cdot 2}\right) \times \frac{\frac{24}{32\cdot 2}}{\frac{8 + 24}{32\cdot 2}} = 7 \text{ units of work.}$$

Suppose, again, the weight of the tool be added to the piston, in order to have the same striking mass as in the first case. Then, $M = \frac{32}{32\cdot 2}$, $M' = \frac{8}{32\cdot 2}$, and $V = 5$, and the work done upon the rock will be

$$\frac{1}{2}\left(\frac{32 \times 5^2}{32\cdot 2}\right) \times \frac{\frac{32}{32\cdot 2}}{\frac{8 + 32}{32\cdot 2}} = 10 \text{ units.}$$

Thus the loss of efficiency due to the interposition of the tool—or, in other words, its separation from the piston—is about 16½ per cent.†

As to the sixth condition, a source of accidental shock of an extremely violent and

* For a description of a drill of this class, see "Warsop's Rock-Drill," in "The Engineer," vol. xxxix., p. 33, January 8th, 1875. This article is illustrated with sectional drawings. Also, Gwynn's American Patent No. 44,722.

† This analysis is from André, and it serves to illustrate the principle; but it certainly seems to even give too favorable results for the class of drills criticised. It does not take into account the battering of the head of the drill and of the piston-rod, which represents work done and lost, nor the breakages of the head and piston-rod, the former of which defects represents money thrown away, and the latter money knowingly and unnecessarily expended in repairs.

destructive character lies in the necessity for a variable piston-stroke. The provision for this variation of stroke allows the piston, under certain circumstances, to come into contact with the cylinder-cover. When, as is sometimes the case, the valve-gear acts independently of the piston, the liability to this accident is greatly increased, and becomes a very serious defect.

In the design and construction of every machine-drill, this tendency of the piston to exceed the proper limits of its stroke should be constantly borne in mind, and means should be employed both to check that tendency and to lessen its effects. A percussion rock-drill operates upon the rock by striking a blow, and it is essential that the blow should be struck with the full force of the stroke. When the rock is very hard, several blows may be struck in succession without either penetrating the rock or breaking away any part of it. A subsequent blow acting on the parts weakened by those already received causes fracture, and the fractured portion instantly becoming detached, the hole is suddenly deepened. The piston will therefore have to advance further at the next following stroke. Moreover, rocks vary suddenly and greatly in hardness, and often contain cavities, besides which they are always more or less traversed by joints.* If all these circumstances are borne in mind, a little reflection will suffice to show that, even assuming perfect feeding to be possible, a percussion-drill could not operate with an invariable piston-stroke, and that the piston must, in the matter of length of stroke, accommodate itself to the requirements of the moment. But as no automatic feed-motion has been devised sufficiently accurate in its action to satisfy the demands of practice, and as hand-feeding is in its nature more imperfect still, the necessity becomes obvious, not merely for a possible variation in the length of the stroke, but for a variation between somewhat wide limits. This renders it impossible to connect the piston in an invariable manner with the valve-gear. Hence recourse has been had to tappet movements to actuate the valve, and in some instances the valve motion has been made wholly independent of the piston. (The principle is the same as in the direct-action steam-pumps, where tappets are almost always used.)

The eighth condition is practically a part of the sixth; rocks often contain cavities, and when a percussion-drill enters one of these, the resistance to the tool is suddenly removed, and this causes the piston to give its extreme length of stroke, and, in consequence of a tendency to exceed the limit, it often strikes against the cylinder-cover. The destructive character of this accident has been already alluded to. A provision against its occurrence consists in allowing ample clearance space at the lower end of the cylinder, or of inserting an elastic buffer.

Now, assuming that practice has decided, as to the intermittent rotation of the drill, that it should be automatic, we have nevertheless seen that there are strong reasons, on the other hand, in favor of a hand feed over an automatic one. Should, however, the feed of a drill be automatic, the tenth condition, that, "if automatic, it shall be regulated by the advance of the piston at each stroke," is one of essential importance. Wood's and also Haupt's momentum feed arose from this principle.

In any mechanism in which a regular progressive action is communicated to the tool, no account is taken of the irregular manner of producing fracture in the rock, of variations in hardness, of the occurrence of joints and cavities, or of the comparative sharpness or bluntness of the cutting-edge of the tool. A certain velocity of progression having been assumed, the inevitable consequence is, either that the tool is not kept properly up to its work or it is pressed forward too rapidly. In both cases, the result is a serious loss of effective work, often accompanied with no less serious delays. With these facts in view, the practical mind will at once note the importance of observing this condition.

As to the eleventh condition, which requires that the machine shall be capable of work-

* The sticking of the drill in the hole from any cause is another source of trouble. It often causes the piston to strike the back head, for steam (or compressed air) packs in front of the piston, and as soon as the drill is freed the piston is forced back with unusual violence and strikes the rear end.

ing with a moderate degree of pressure, it is one that must tend greatly to promote the successful employment of rock-drills actuated by compressed air. (See foot-note, p. 212.) The notable loss of work occasioned by a high degree of compression of air by steam, the heat generated by the process, the increased difficulty of storing and conveying the air, and the intense cold produced by its expansion when exhausted from the machine, all these consequences of high compression, with others of a less important character, tend to render the employment of high pressures objectionable.

So much for rock-drills as we know them now. In regard to the "coming drill," as indicated by the patents and the results of practical application, it is not easy to predict it. We may, however, in a few words, indicate the direction of the paths taken.

The general feature is settled—*i. e.*, the Fowle type of driving the drill directly is the one that will be used. With the exception of the Dubois-François, it is pretty well settled that a self-acting spiral of some form will be adopted. The spiral bar first patented by Low in England, and perfected by Doering and Darlington, is the style adopted on nearly all short, portable drills. In regard to the Dubois-François rotation, by means of two small pistons (see English Patent, 1872, No. 1398), it is doubtful if it will be substituted for the spiral bar now so generally in use; and we are not sufficiently acquainted with it to judge whether it is better, on the long European tunnel-drills, than a suitable spiral self-acting bar arranged, say, like Burleigh's (American Patent, No. 59,960), but it certainly serves a good purpose on the Dubois-François machine. The indications are that a simple hand-feed, with no indicator to guide the operator except that which results from the necessary action of the machine, will be universally adopted. As yet, we cannot predicate with certainty as to any particular valve movement. Two general plans are undergoing a trial: viz., the tappet and the supplementary valve. Mr. Burleigh gave it as his opinion, in the case of the Burleigh Rock Drill Company *vs.* George W. Lobdell, *et al.* (June 3d, 1874), that "the introduction of auxiliary valves is of itself enough to render a machine comparatively worthless." Notwithstanding this high authority, we see that the Wood drill in America and the Dubois-François in Europe, both of which have a supplementary valve, have a good reputation. This device was particularly recommended by Low in England, in 1865, and many efforts have been made to perfect it, but whether the failure was due to it or to other parts of the machines, we cannot say. It is certain that this class of machines have come into repute more recently than the tappet machines.

As for the chucks, there seems to be no indication that any device yet known is becoming a general favorite.

CHUCKS AND DRILL-BITS.—Every detail of a rock-drill is important; the smallest piece must be considered. A single piece which does not perform its functions properly, or which is too liable to break, may condemn a whole machine. It would be interesting to the inventor to trace the history and discuss the principles of each of the principal functions of the machine—the valve movements, the feed, and the rotation, but space forbids our entering upon so much of detail. We will, however, add a few words upon chucks and bits.

The most natural way of fastening the drill to the piston-rod would seem to be by means of a set-screw, but experience shows that the excessive jar to which the drill and rod are subjected loosens the screw, and hence this method is inoperative. We notice that, in a great majority of the English patents, a set-screw is shown in the drawings, and this fact alone shows that they are designs upon paper. Low, who probably did more *practical* inventing than any other man in England, enlarged the drill-shank so as to leave a shoulder 4 or 5 inches from the end. This shank was entered into a socket in the end of the piston-rod, and a nut divided into halves was screwed into the end of the socket and against the

shoulder of the shank. We have been informed that this device was tried in the Brooks, Gates, and Burleigh drill at Hoosac Tunnel, but our information is not sufficiently specific to warrant us in asserting that the device was the same as Low's. In the two great tunnels in Europe, the Mont Cenis and St. Gothard, a simple key was and still is used. The drill-shank is round and about 1¼ inches in diameter, and 5 or 6 inches long. Just in front of the shank the stud is enlarged to some 2¼ inches (or more) in diameter, and turned so as to make a square shoulder, which buts against the end of the drill-bar when in use. The key is a strip of iron some 7 or 8 inches long, about ½ inch thick, and varying from ½ inch to 1¼ inches wide. This is driven in, and the small end is bent over so as to prevent its getting out when drilling. To remove the drill, the miner straightens the key and drives it out. This key is liable to break frequently, but as the engineer says, "It is simple and easily replaced. We keep a large quantity on hand, and find that it answers our purpose better than any other that we have tried." In regard to this device, we observe that it would be fatal to the systems used in this country. While it answers for machines used on works which occupy ten or twelve years in construction, it will not answer for our portable drills. Drills in this country are designed not merely for tunneling, but for mines, excavations, and quarries. The extra cost of enlarging the shank would condemn the whole system in the eyes of many. Then, too, the key is so long that it could not rotate in the drill-slides as ordinarily constructed. Hence our inventors have sought different modes of securing the drill. The general plan seems to be to hold the drill-shank by means of friction induced by bolts, in which the bolts are not forced directly against the drill-shank.

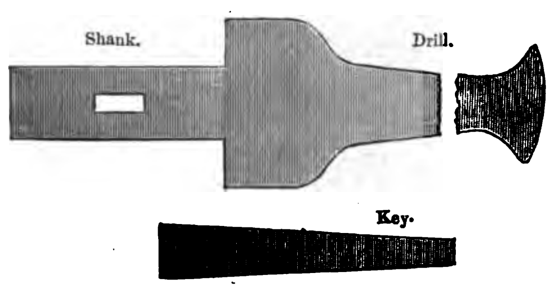


FIG. 97.

On May 18th, 1867, Thomas Doane, formerly Chief-Engineer of Hoosac Tunnel, made an application for a patent on a drill-chuck, shown in Fig. 98, but for some reason it was not

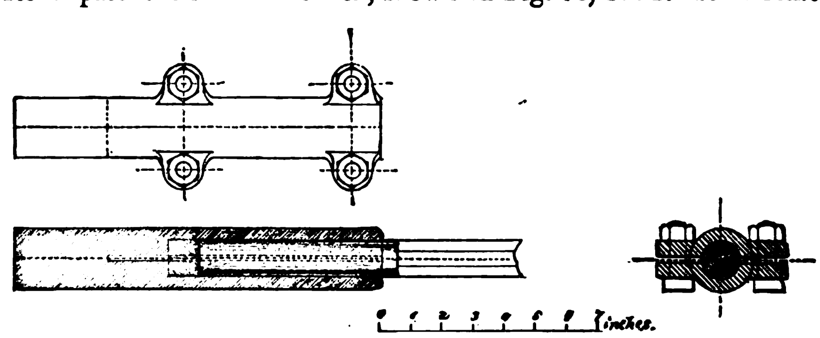


FIG. 98.

CLUTCH FOR ATTACHING DRILL-BAR TO ROCK-DRILLS, HOOSAC TUNNEL.

Invented by Thomas Doane. (Designed November 9th, 1866.)

issued. This is called a split chuck. The bolts forced the two parts together and held the drill firmly. One quite similar to this, patented by a Mr. Hall (American List, 1868, No. 80,406) has been largely used on the Burleigh drill. In some cases, a taper bolt or bolts have been used (see American List, patents Nos. 80,386 and 145,364). One of the most novel designs is that invented by Wood & Robinson, in which the momentum from the blow tightens the drill (see the reissue of No. 71,329 and Fig. 95).

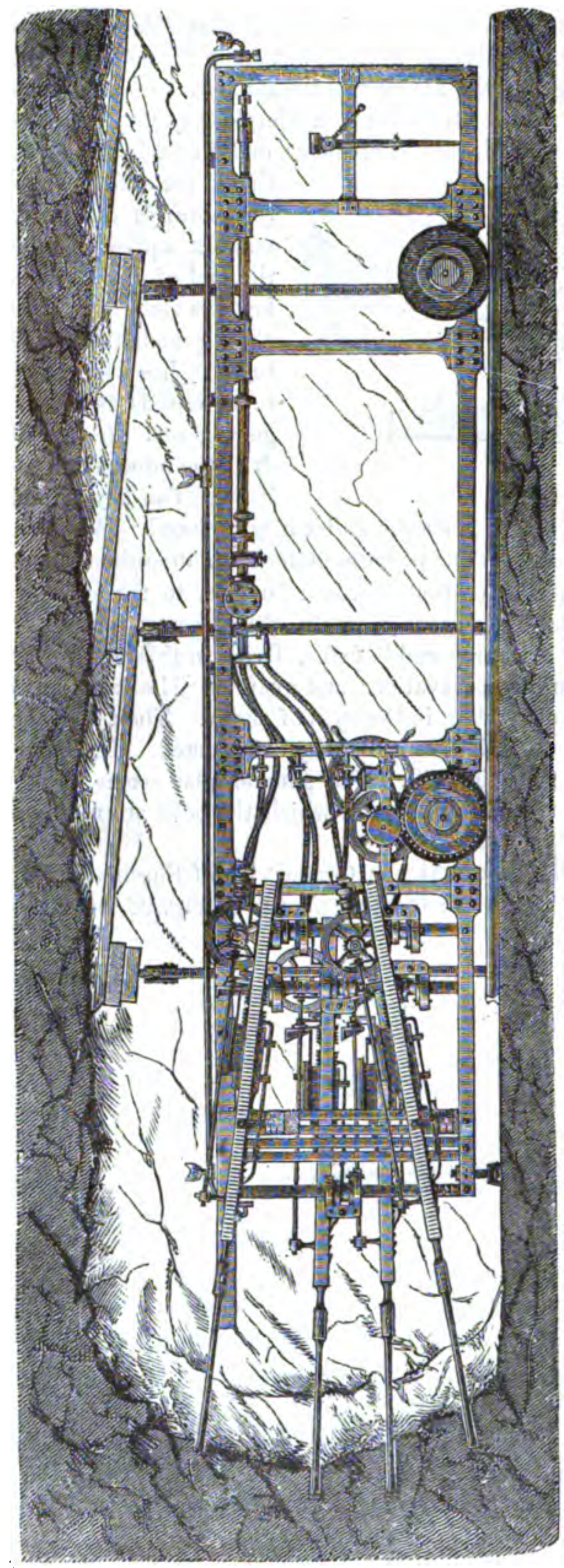


FIG. 99.
SOMMEILLER DRILLS MOUNTED IN HEADING.

Bits.

It was soon found that an ordinary plain bit in a machine was liable to make fluted holes. Such holes cannot be drilled as rapidly as round ones, and they are especially severe on the rotating device. Fowle obviated this difficulty by making an **S** bit (see his caveat, 1849). Low, of England, made **+** bits, **S** bits, and **Z** bits, in 1863–'65. Gates made a **+** bit in which the space between the wings of the bit were unequal (see American patent, 1866, No. 55,277. For three or more radial edges, see No. 47,870). Chisel-bits or reamers have also been devised for the same purpose (see No. 48,785). Bits have also been made in which the edge was beveled like a chisel, so as to produce an automatic rotation by the striking of the tool (see Nos. 49,129 and 158,704).

It has been found that a plain bit may make a hole nearly round in hard, homogeneous rock, but that in soft rock even the **+** bit will sometimes make fluted holes, but the **Z** and chisel or reamer bits can be made to cut true holes in all cases. The **Z** bit seems to be of the best form theoretically for cutting, for the greater part of the cutting-edge is around the circumference of the hole where most of the cutting is to be done. But the greater liability to break and the greater difficulty of repairing and sharpening of this **Z** bit have made the **+** more acceptable where the other forms were not actually necessary. (See p. 259 for notice of the "double-gouge" bit of the "Victor" drill, and pp. **114** and **115** for descriptions and illustrations of hand-drill bits.)

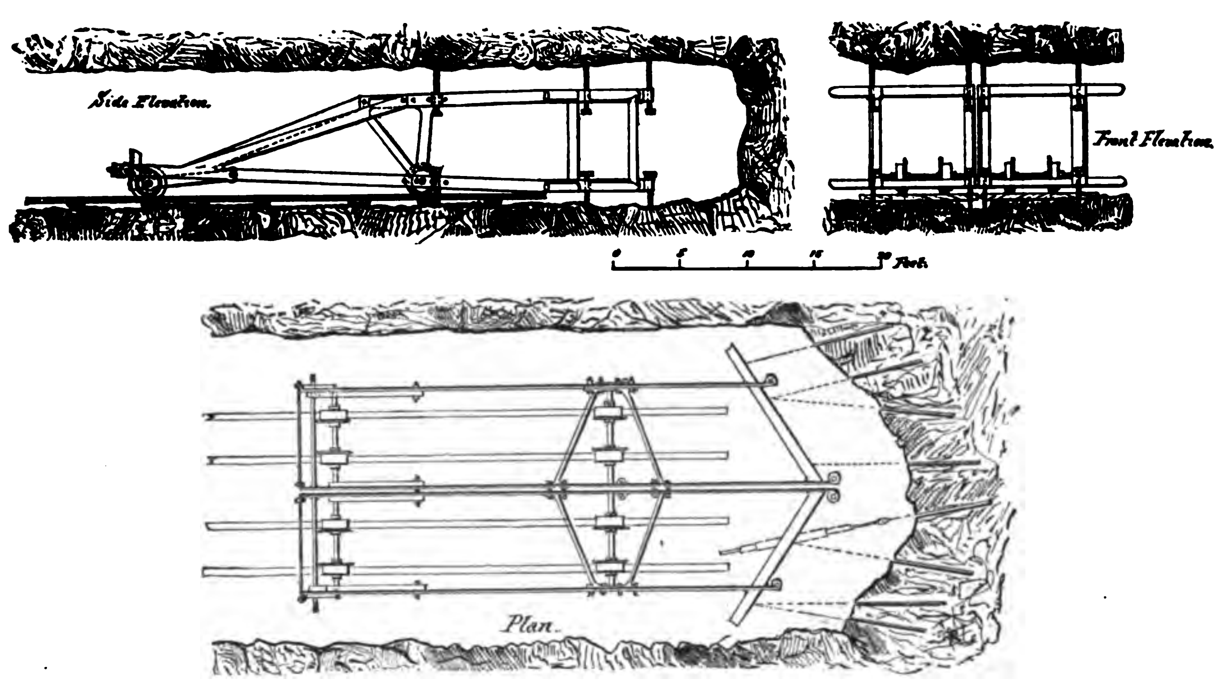


Fig. 100.

THOMAS DOANE'S DRILL-CARRIAGE. (Patented Dec. 10th, 1867.)

(Used in early drilling at Hoosac Tunnel, and to the end of the work.)

Drill-Carriages.

As to the drill-carriage, it is one of the points to which especial attention should be paid in heading-work. Fig. 99 shows the drill-carriage used by Sommeiller at the Mont Cenis Tunnel. Fig. 100 shows a carriage patented by Mr. Thomas Doane, for use at Hoosac

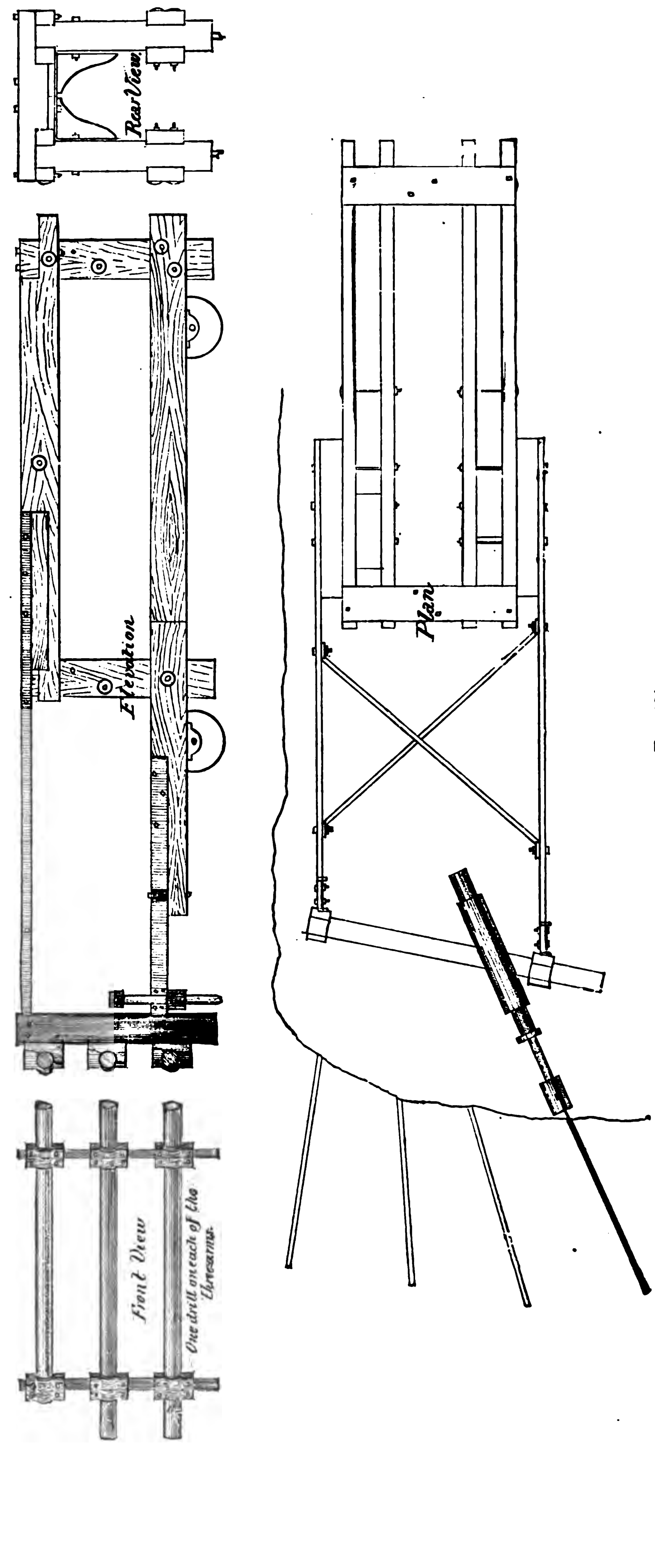


FIG. 101.
DRILL-CARRIAGE USED IN THE NESQUEHONING AND MUSCONETCONG TUNNELS.
(Scale 4' = 1''.)

in the early days of machine-drilling there. Fig. 101 shows the style of carriage used at Nesquehoning and at Musconetcong, there being two carriages in a heading, one on each side. At Musconetcong, six drills were used in the heading, three on a carriage.

Fig. 102 shows the carriage patented and sold by the Burleigh Rock Drill Company.

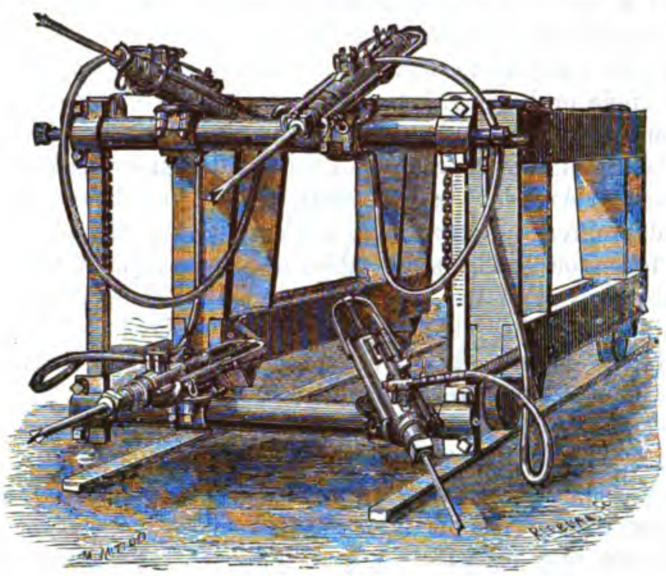


FIG. 102.
BURLEIGH FOUR-DRILL CARRIAGE.

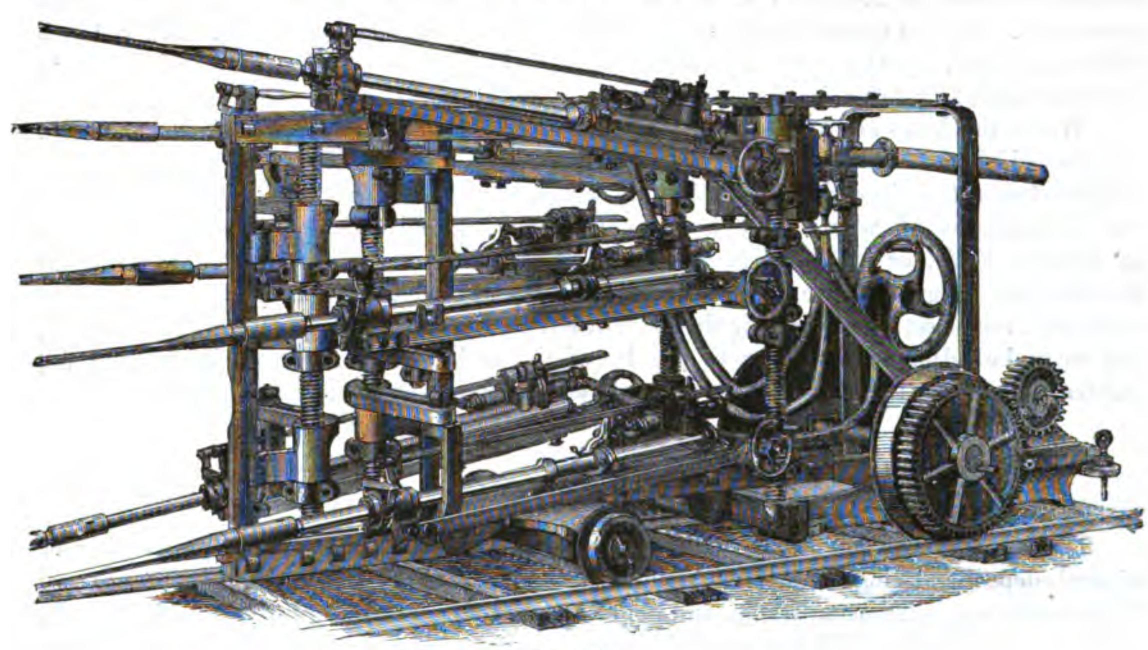


FIG. 103.
DUBOIS-FRANÇOIS DRILL-CARRIAGE.

The arrangement of the Burleigh tunnel-carriage is such that, by raising the bar upon which the drills are mounted, an open passageway *through the carriage* is obtained, through which

the cars for removing the rock can pass, or the loose rock thrown out by the blast can be thrown between the tracks, and the carriage run forward *over the rock* to the heading, and the work of drilling prosecuted while the rock is being removed. (And see p. 237.)

Fig. 103 is the Dubois-François carriage used in the St. Gothard advance heading. As abroad, the policy of a small, narrow heading is advocated, the carriage is necessarily small and compact, and is not arranged to afford much adjustment as to the direction of the drill-holes, the European plan being, as to rule, to drill the heading-holes normal or almost normal to the face, with no angle or bearing. (See end of Chapter IV. and also Chapter VI. for a further elaboration of this question.) As to the relative merits of the two systems, it will be seen, by inspecting the tables of progress of tunnels driven by machinery in Chapter VI., that the rates attained in America average nearly the same as those in Europe up to 1882. For the same lineal progress, however, more work is done by the American system, owing to the larger area taken out. The same tables also, as compared with those of tunnels driven by hand labor, given at the end of Chapter IV., show that the relative rates of progress with machine and hand labor may at the present day be safely assumed as five to one in tunnel-headings where the work is well pushed and the rock firm. But in soft rock, the ratio is much less than for hard rock. This ratio, here shown to be a safe one by the actual tables of progress given, has also been assumed on more general grounds by Ržiha in his recent work, "*Eisenbahn- Unter- und Oberbau*," p. 423 (1876). Further, in cases where work is to be pushed, at least six machines should be used at the face of the heading. Moreover, a sufficient number should be kept on hand to allow for breakages. False economy in this respect may essentially impede progress. Furthermore, in hard rock it is best to use machines of larger, and in easy rock machines of smaller cylinder diameter. At Musconetcong, some twenty-six to thirty machines were kept on hand; as from eight to nine were used at both the east and west heading, this left a margin of about one third spare ones. At this tunnel also hard syenitic gneiss was met, and at first 3½- and then 4-inch drills were tried by the contractor, Mr. Charles McFadden, but finally the 5-inch Ingersoll drill was settled on as by far the best size for use in such rock.

Where machines are worked in a heading, and the heavy explosives used, less attention may be paid to the individual location of each hole than in hand-drilling. The holes should be placed so as to help each other and attain a large common effect. This is especially the case in heading-work where there is a premium paid on contracts according to the rapidity of advance made, or where, as in most railroad-tunnels, speed of completion is the great desideratum. Again, where the price paid is simply per cubic yard, as in open-cut, quarry work, etc., the direction of the hole drilled will not be a matter of comparatively regular rule, but must be adjusted according to the lay of the rock; moreover, in work of this kind, lighter drills—*i. e.*, those of 3- and 4-inch cylinder—have been found economical.

The Diamond-Drill.

The diamond-drill has been chiefly applied in the United States to the prospecting of mineral deposits, boring of artesian wells, and shaft-sinking by the "long-hole" * process. For prospecting, it is incomparable, and hence it is of the greatest interest in mining. In general, for boring long holes at an angle, or even horizontally, the drill has no rivals of any kind.

* See paper by Echley B. Coxe, published in the Transactions of the American Institute of Mining Engineers, vol. i., p. 261, and Drinker on Tunneling, p. 756, on this system of sinking shafts by drilling holes of from 250 to 800 feet deep, which are then filled with sand, and blasted out in stages.

At the Mary copper mines of Ducktown, Tennessee, three bore-holes were put down, to determine, if possible, the position of the copper deposits which had been lost. In the first case, a vertical hole was sunk to a depth of 75 feet without discovering the ore. Another was then sunk 300 feet in a direction at right angles to the dip of the deposit without striking any paying bodies of ore, and at last one was sunk 488 feet, striking a rich body of copper ore in the iron pyrites.

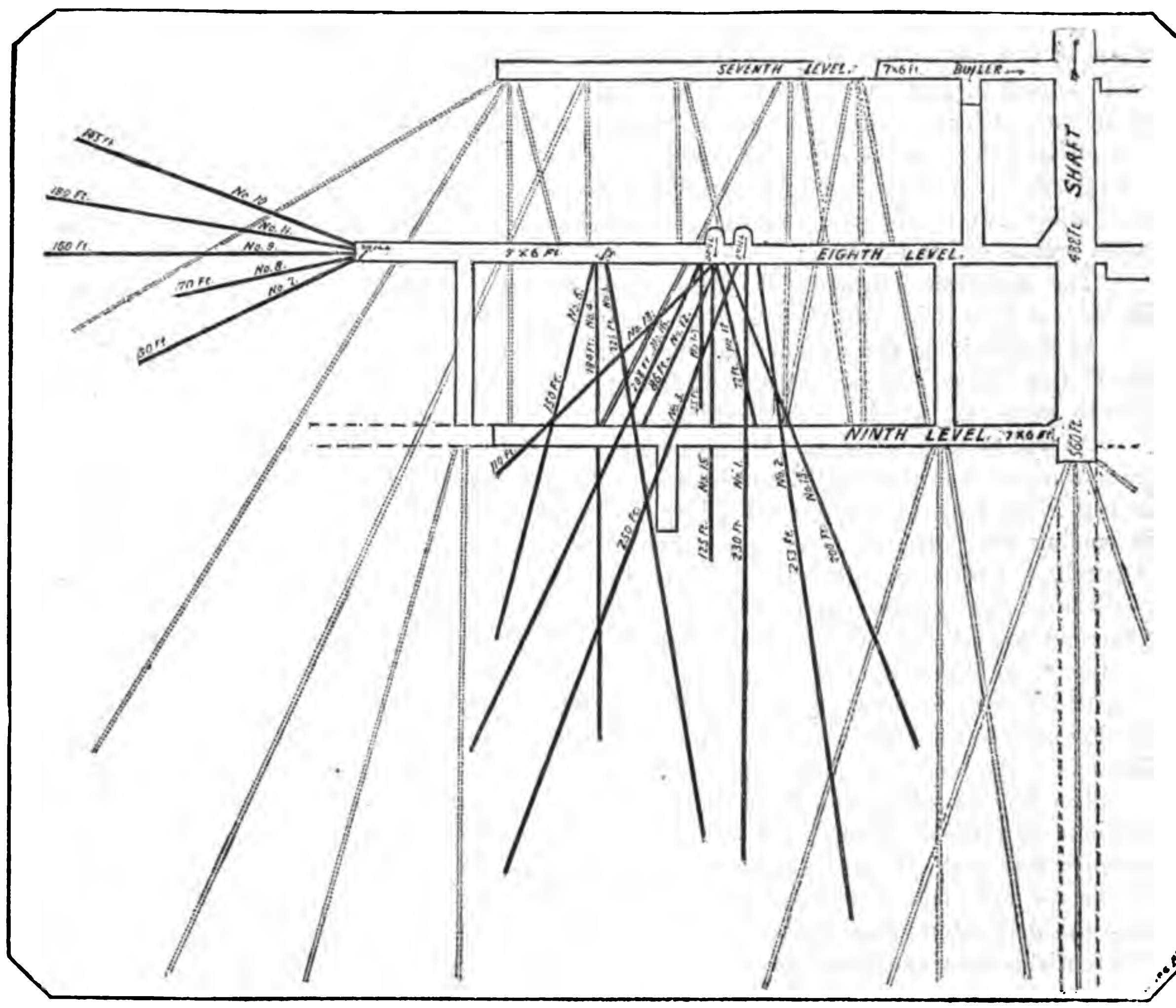


FIG. 104.

PROFILE SHOWING BORINGS IN THE SILVER ISLET MINE, LAKE SUPERIOR COPPER REGION.

The Silver Mining Company of Silver Islet, Lake Superior, prospected quite largely with the diamond-drills during the winter of 1875–'76. The borings were all carried on at a depth from the surface of 488 feet in a level 7 by 6 feet. The borings (18 in number) were made at various angles, and were from 70 to 253 feet in length, the total distance bored being over three thousand feet, taking in time about six months.

Three bore-holes have been put down by Mr. O. J. Heinrichs at the Midlothian colliery, Virginia. These were respectively 1142, 922, and 715 feet deep, costing per foot $3.62, $1.91, and 94 cents.

When the question of boring short holes in open work or tunnels is considered, experience has shown so far that the total cost of working (including plant) with the diamond-drill exceeds that by percussion-drills. As to the connection of the diamond-drill with tunneling proper, it has been used in California in tunnels driven in connection with hydraulic mining; also, lately (during 1872–'75) two tunnels have been driven by the Pennsylvania Diamond-Drill Company in the Schuylkill coal region, Pennsylvania. One of these tunnels was through conglomerate, the other through sandstone, the latter being decidedly the more refractory of the two. It was so hard that an average advance of only about 9½ feet per bit was obtained in 300 feet of drilling; that is to say, the bits would be worn smooth in drilling 9½ feet each, and have to be replaced by new ones. In the conglomerate, under like circumstances, single bits would drill 40 and 50 feet before giving out. For driving these tunnels, the improved drills used in shaft-sinking were employed. The "long-hole" process was used for portions of the sides and bottom with good results, leaving the surface beautifully straight and smooth when compared with the results obtained by the usual process of hand-drilling.

The American Diamond Rock-Boring Company supplied eighteen drills to Henry Meiggs, of Peru, who used them in the tunnels of the Lima and Oroya Railway.

In England, the diamond-drill has been applied in a number of tunnels, among others the Clifton Tunnel; Messrs. Beaumont & Appleby have taken out a patent for its application to tunneling, which is described below.

As will be seen below, the American types of the diamond-drill are much lighter and more compact than the English machines; this is particularly the case with the drill shown in Fig. 104½, built in the year 1877 by the Pennsylvania Diamond-Drill Company, which is coming into general favor. A number of these machines have been even sent to Australia. Four companies own the patents under which M. Leschot, the original inventor of diamond rock-boring, controls his inventions in the United States. These are the American Diamond Rock-Boring Company, of Providence, R. I.; the Pennsylvania Diamond-Drill Company, of Pottsville, Pa.; the Northwestern Diamond-Drill Company, of Chicago, Ill.; and Messrs. Severance & Holt, of San Francisco, Cal. The American Company and the Pennsylvania Company made separate exhibits of their drills in Machinery Hall, at the Centennial Exposition, Philadelphia, 1876.*

The American Diamond Rock-Boring Company showed one of their prospecting drills mounted on vertical boilers. The drill is driven by means of two oscillating cylinders set at an angle with each other, and working the shaft through the intervention of two bevel-gears. Above the cylinders is a drum which can be turned by the engines, and which is used to hoist the drill-tubing from the well. The feeding of the drill is accomplished by means of differential screws, and is uniformly progressive, no matter what variations there are in the nature of the rock passed through. A small drill made for open quarry-work was also shown.

The engine, feed arrangements, and the drill-rod are held by two parallel legs, while a third one, movable at pleasure in several directions, forms a tripod-stand with the other two. The drill-rod passes through the centre of the cylinder of the engine, which, being a rotary one, turns the drill without the intervention of cranks or gearing. The drill is fed downward by two worm-wheels which engage a screw on the upper part of the shaft, which latter passes through a gallows-frame on the top of the two parallel standards. When in operation, the progress of the drill is regulated by friction-clutches on the worm-wheels.

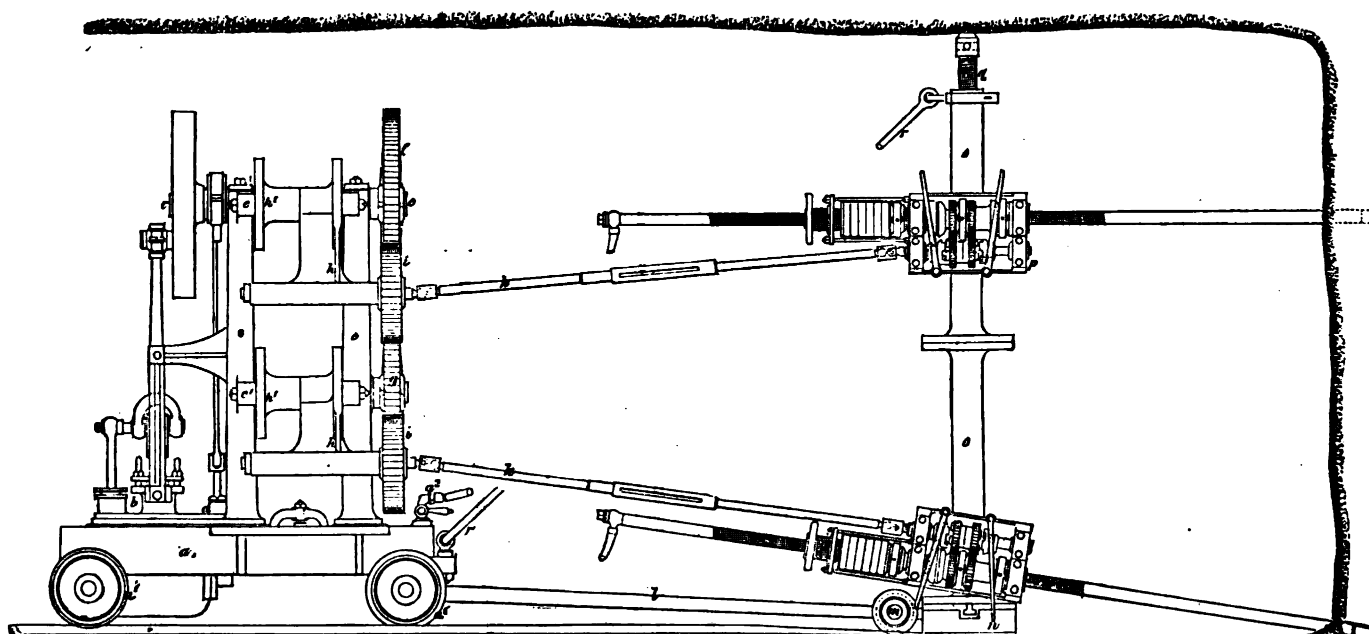
During the construction of the Illinois State Capitol, it was found that unless the stone columns used in erecting it were made lighter, much inconvenience and extra expense would

* See "Engineering and Mining Journal," New York, vol. xxiii., No. 10, p. 150, March 10th, 1877.

result. To get rid of this difficulty, a large size diamond boring-machine was constructed, which cut a 24-inch hole and extracted a 22¾-inch core from each of 260 of these columns. A piece of one of these cores was shown in the exhibit of the company.

The Pennsylvania Diamond-Drill Company exhibited one of its rock-drills which is provided with the hydraulic-feed. The engine which drives the drills is one of Root's patent square engines, connected to the drill-shaft by means of bevel-gears. On either side of the drill-shaft are two hydraulic cylinders connected at two places by cast-iron frames. Piston-rods on the lower side of these cylinders are fastened to a cross-head, through which also passes the drill-shaft. The drill-shaft, when working, is held by this cross-head, so that when the piston-rods are forced downward by the admission of water under pressure, the bits are pressed against the rock with corresponding force. The advantage of using this form of feed consists in the use of a constant pressure, no matter what be the varying nature of the rock passed through; it insures very rapid progress in boring through soft material. When drilling in rock, however, which contains seams or empty pockets, the use of the hydraulic-feed might not be the best, as the sudden shock to the diamonds in the bit, when driven through such empty space, might break them. It is claimed that the screw-feed is preferable in the hands of an inexperienced man in such material.

A small drill for open quarry-work, shown by the Pennsylvania Company, differed from one shown by the American Company in being driven by two small oscillating engines.



Side Elevation.
FIG. 104¼(a).
BEAUMONT & APPLEBY'S ADAPTATION OF THE DIAMOND-DRILL TO TUNNELING.

The diamond-drill as now manufactured with the improvements originating with the Pennsylvania Diamond-Drill Company, and as yet principally used in the United States and Canada, bores a straight, smooth hole, *of even size down to the bottom.* This, it is well known, has been hitherto impracticable with other drills. The importance of thus permitting the passage of the bulk of the charge of explosive to the very bottom of the hole is easily seen and appreciated.

To revert to the application of the diamond-drill to tunneling proper, Figs. 104¼(*a*) and 104¼(*b*) show Beaumont & Appleby's patent in England (No. 1682, A.D. 1868). Fig. 104¼(*a*) is a side elevation and Fig. 104¼(*b*) an end view of the driving apparatus; *a a* is the hollow bed-plate mounted on wheels a^1, so as to traverse freely on rails to and from the working face; in it there is mounted a small air-engine with a vertical cylinder *b*, driving, by means of a connecting-rod, the shaft *c*; *d* is a small pump, which the engine also drives; it draws water by means of a flexible suction-pipe, and forces it into an air-vessel in the bed-plate, from whence it issues by four nozzles a^2 a^2, provided with stop-cocks, and by flexible tubes is conveyed to the borers. The shaft *c* is supported from the bed-plate *a* by two standards *e e*, and at the outer end it carries a spur-wheel *f*, gearing with another similar wheel *g* on an axis, the bearings of which the standards also carry. On the axis of this wheel, and also on the shaft *c*, two arms *h h* are mounted between the standards; they carry at their outer ends pinions *i i*, gearing with the wheels *f* and *g* respectively. These arms are able to turn upon their axes, and can be set to radiate from them

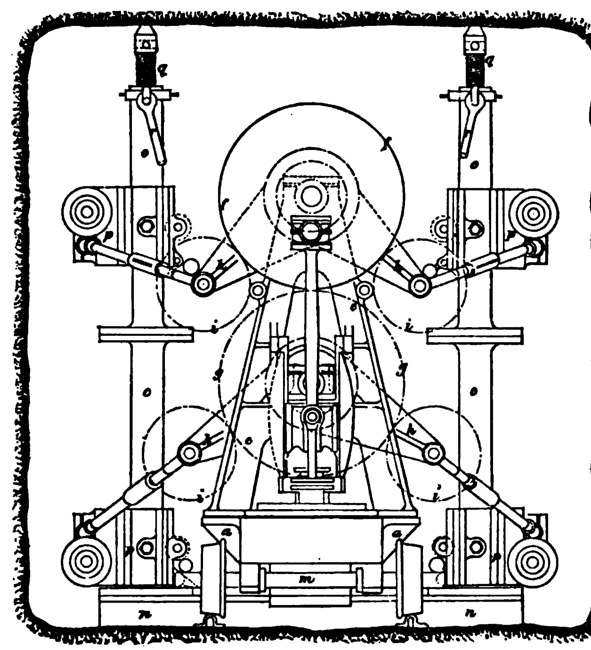


FIG. 104¼(*b*).
End elevation of Fig. 104¼(*a*).

in any desired direction. Each of the arms *h* has a disc h^1 upon it, concentric with the axis, and in the face of this disc is a circular groove, dovetail in section; they receive the heads of screw-bolts which pass through lugs e^1 on the standards *e*, so that, by means of clamping-nuts on these bolts, the arms can be locked in any position. From the axes of the pinions *i* motion is given to the borers by means of shafts *k*, which are connected with these axes, and also with the driving axes of the borers, by means of universal joints; the shafts *k* are also made telescopic. From the forepart of the carriage *a*, coupling-bars *l* pass to the axis *m*, which has also flanged wheels at its ends to run upon the rails. *n* is a casting connected with the axis *m* and able to turn about it. This casting, when the machine is at work, rests upon the floor in front of the working face; it is planed on its upper surface, and a T-formed groove runs from end to end of it. *o o* are columns standing upon this casting; they can be clamped to it at any part of its length by bolts, the heads of which are received into the T groove, and which project through holes in the base of the column; these holes are slotted so as to admit of the column being turned partly around and so clamped. Each column is made in two lengths, clamped together by flanges having slotted holes in them, so that the one part of the column can be turned partly round upon the other part. The columns each have two slides *p*, one on each of its sections or lengths, and these slides carry the borers; they can be traversed up and down upon the columns and clamped in any desirable position. The columns are square in section, and have racks running from end to end of them, with which pinions on the slides gear; the slides have also locking-pawls taking into the teeth of the rack, and which retain them at any elevation to which they may be raised; they also have clamping-screws rigidly to fix them to the columns when the borers are at work. On each slide *p* is a face-plate

against which a corresponding face on the frame of the borer is applied, and the two are clamped together by bolts having dovetail heads entering a circular groove in the face of the slide *p*. By this arrangement, it will be seen that the borers may be set to bore into the working face in any position and in any required direction, for the position of the borer can be adjusted in a horizontal direction by traversing the column *o* along the casting *n*, and in a vertical direction by traversing the slide *p* upon the column, while the inclination of the borer in a vertical plane can be adjusted by setting the face-plate of the borer-frame to the desired position upon the face-plate of the slide *o*, and the inclination of the borer in a horizontal plane can be adjusted by turning the column *o* itself partly round upon the casting *n*. *g g* are screws at the upper ends of the columns; they are pointed at their ends, and are screwed out into the roof to steady the columns in working; *r r* are stays passing from the tops of the columns to the bed-plate *a*. When the apparatus is required to travel to and from the working face, the stays and the telescopic axes *k* are removed, and the columns *o o* are laid down till their upper ends rest upon the bed-plate *a*; the casting *n* will then be raised off the ground, and be supported on the wheels of the axis *m*.

We will now turn to the American type. It will be at once seen, by inspecting Figs. 104½ (*a*) and 104½ (*b*) that the American drills are much more compact and easily adjusted than

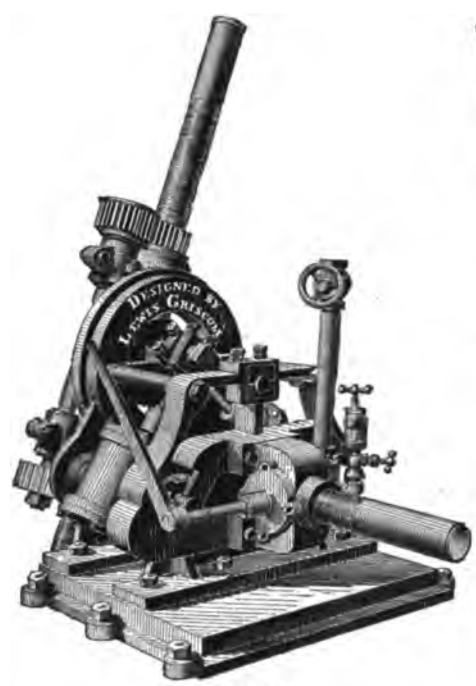


Fig. 104½(*a*).

Fig. 104½(*b*).

DIAMOND-DRILL MANUFACTURED BY THE PENNSYLVANIA DIAMOND-DRILL COMPANY OF POTTSVILLE, PA.

Can be adjusted for heading or shaft work, and will drill at any angle. Dimensions, 27 inches long, 24 inches wide, 22 inches high; steam cylinders, 4½-inch bore; running speed, 500 revolutions per minute; spindles take 1⅝ or 1⅞ inch drill-rods; fitted with either screw or hydraulic feed; weight of machine complete, 500 pounds.

the heavy, costly European type. These figures show the improved diamond-drill manufactured in 1877 by the Pennsylvania Diamond-Drill Company, of Pottsville, Pa. By im-

provements recently made, these drills for open-cut or quarry work have been so much lightened that they are now claimed to be as portable as the ordinary percussion-drills. The lightest drill built by this company (exhibited at the Centennial) weighed only 290 lbs.

Fig. 104½(*c*) shows the drill arranged for shaft-work. Four are generally used in sinking large shafts. Further improvements are being introduced to fully adapt these light drills to heading- and tunnel-work in general, and it has been proposed to apply them in connection with percussion-drills in the centre-cut system of blasting. The centre-cut system will be found described in detail, p. 310. Briefly, it consists in drilling a set of holes from ten to twelve feet deep, meeting at an angle. These, charged with nitro-glycerine or dynamite, bring out a centre-cut which is then squared up by subsequent side-rounds (Figs. 118 and 119). With the diamond-drill, the plan proposed is to drill long holes around the sides, roof, and floor of the heading; the core will then be taken out by centre-cuts, the holes for which will be drilled by percussion-drills, and the sides can then be brought in and the roof taken down by shots in the long holes, probably ten or twelve feet of a hole being blasted per round. (The side-holes, when centre-cut blasting is used, are generally of this length.)

Also it is claimed that the diamond-drill can be used to advantage in taking up the bench of a tunnel in drilling the holes marked 3 and 6 in Fig. 121. So far as experience has gone in the matter of tunnel-work, it would appear that a judicious application of the diamond-drill in tunneling, as in shaft-sinking, would tend to accelerate the rate of advance attained, but probably it would be at a greater cost than with percussion-drills alone, just as the direct outlay in using percussion-drills in turn is found to be more costly than hand labor. It probably will be the case, however, that the cost of the plant in diamond-drilling will in time be considerably reduced; this seems likely, from the fact that excellent portable diamond-drills were sold in 1877 by the American companies at from $750 to $850; whereas, a few years since none could be bought under $1500 to $2000.

One of the most thorough records we have of the cost of work by the diamond-drill is in a paper read before the American Institute of Mining Engineers, June, 1876, by Mr. Lewis A. Riley, Chief Engineer Locust Mountain Coal Company, Pa.*

The results given were obtained, during the years 1875–'76, by means of two drilling-machines belonging to the Lehigh Valley Coal Company, and operating on their coal land in the Mahanoy, Lehigh, and Wyoming regions. The majority of the holes were put down for the purpose of proving the lower veins of the coal series; they had to encounter the harder rocks of the coal formation, much of the distance being through the lower conglomerates, going, in some cases, through the coarse egg conglomerate, the foundation of the coal deposit, and to the green stone and red shale which underlie it. The lower sand-rocks and conglomerates are among the hardest known to geologists, and present a formidable resistance to the exploring-drill. This fact must be taken into consideration, in comparison of the cost of drilling. An instance was observed where one bit, in boring in the upper or softer rocks of the Wyoming region, drilled some 280 feet without resetting, while in the Lehigh and Mahanoy regions, in the lower and harder rocks, bits set with the same quality of diamonds would only bore from 3 to 20 feet before being worn out.

The boring was done with a No. 2 drill, shown in Fig. 105. It was of an improved design, of large size, with oscillating engine of fifteen horse-power, and performed its work in a highly satisfactory manner. During one year, it drilled nine holes, of a total length of 4562 feet, without being once repaired, or incurring any cost outside of the ordinary running expenses. The deepest hole bored was 900·6 feet long, so that its capacity of 2000 feet, as given by the builders, Messrs. Allison and Bannan, of Port Carbon, was not tested.

* "Engineering and Mining Journal," vol. xxii., No. 15, p. 233, New York, October 7th, 1876.

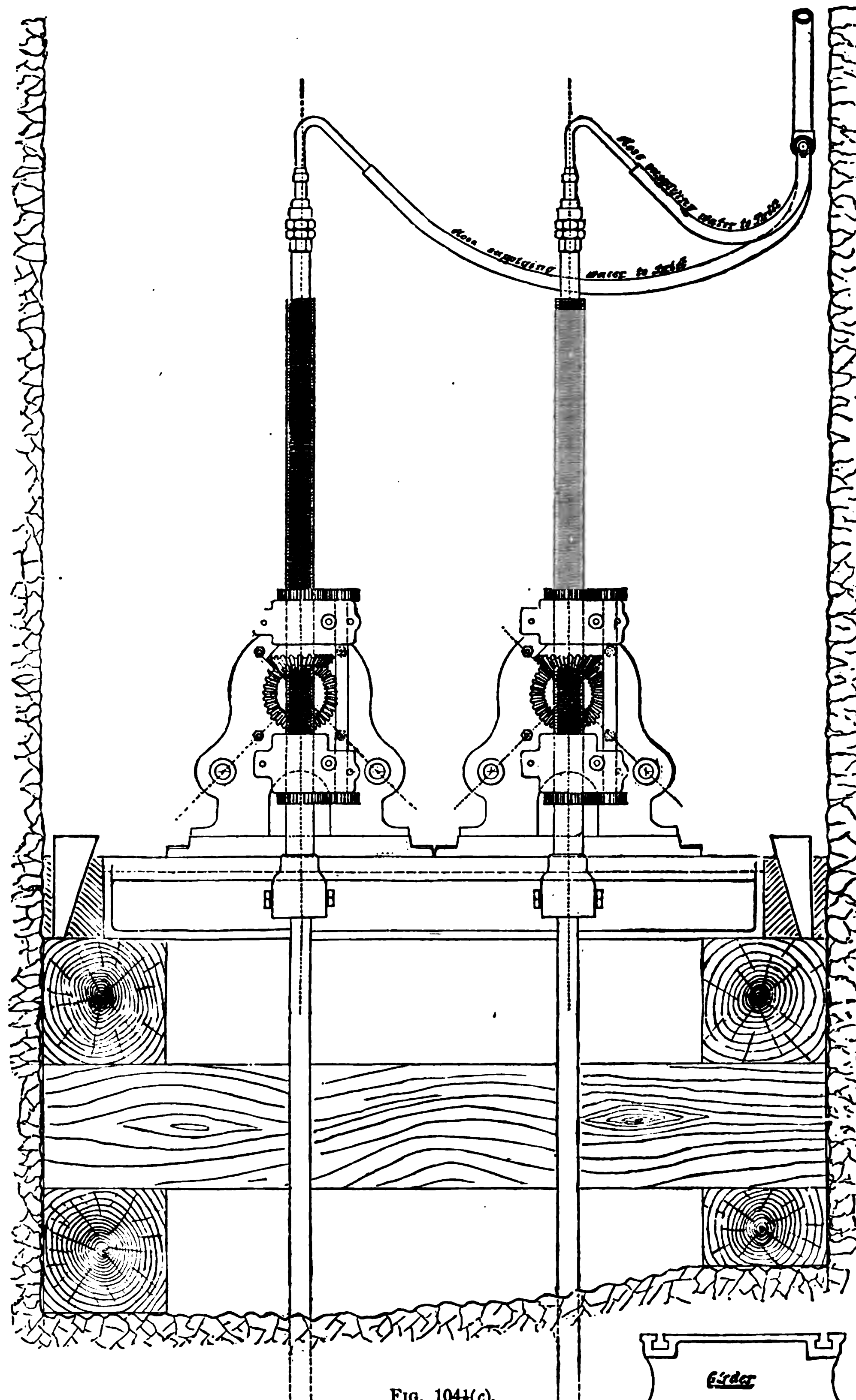


Fig. 104½(c).

SHAFT-SINKING BY THE DIAMOND-DRILL OR "LONG-HOLE" PROCESS. (Scale, 3′ = 1′.)

The cost of the drill, with movable boiler, sixteen horse-power, and 1000 feet of two-inch drill-rods, was $3872.40. In addition to drill, boiler, and rods, the outfit, with each drill, comprised a set of machinist's and fireman's tools, a portable house, and a stock of dia-

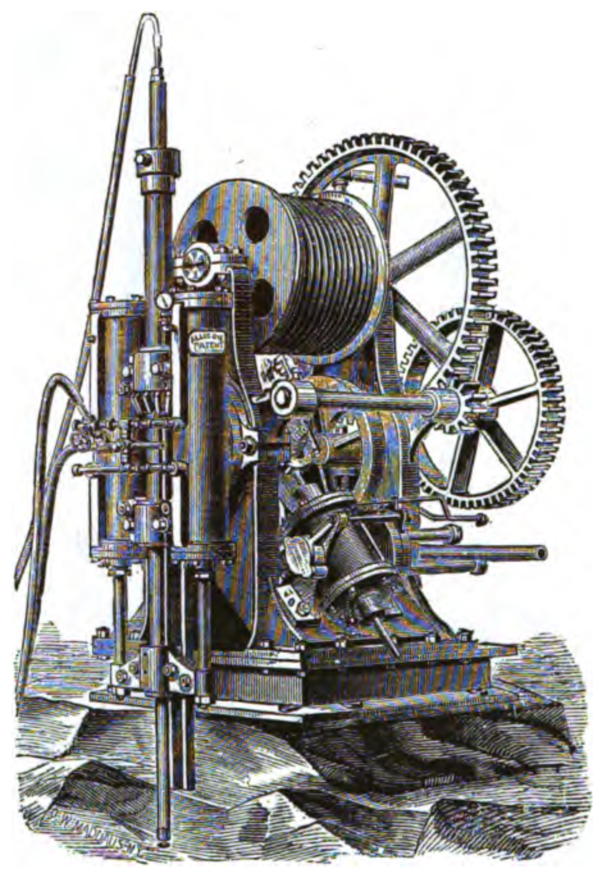


Fig. 105.

IMPROVED DIAMOND DRILLING-MACHINE, WITH ALLISON'S PATENT HYDRAULIC-FEED.

Steam cylinders (oscillating), 6-inch diameter, 6-inch stroke, central spindle, 3-inch diameter, can be fitted to take rods from $1\frac{5}{8}$ inches up to $2\frac{1}{4}$ inches diameter. Hydraulic-feed cylinders, 5 inches in diameter, 2 feet run; improved hinged swivel-head swings to one side, out of way of drill-pipe. Spiral-grooved hoisting-drum, 20 inches diameter, 16 inches long, grooved to take $\frac{5}{8}$- or $\frac{3}{4}$-inch wire rope; drum double-geared, so as to hoist heaviest rods with single rope. Reversing valve on engine, so as to hoist and lower at will. Weight of machine, set up complete, 3486 lbs. Weight of machine, without drum-gear and swivel-head, 2195 lbs. Will drill a 2-inch hole 2000 feet deep.

monds sufficient to keep about five bits set for each machine, making a total cost of each drill and outfit of about $5000.

The labor force consisted of a foreman, engineer, and fireman with each drill, and an assistant superintendent in charge of both drills. If it were not for the work and time of removing the rods, once for about every 10 feet of boring, to obtain core, two men would have been ample; as it was, three men were found to do the most work at the least cost per foot. A pitch-indicator was devised by the assistant superintendent, consisting of an attachment to the drill by which the last piece of core which remained unbroken from the bed-rock, when the drill stopped, was brought to the surface in the same position as when broken off, by the rods being raised by hydraulic pressure; then, if this piece of core was marked by a seam in the strata, the dip and direction could be obtained accurately.

The total length of holes bored was.............	9901·9 feet.
The average progress per day was..............	18·9 "
The average cost per foot was..................	$2.22

This included labor, diamonds, fuel, water supplies, repairs, expense of moving from place to place, etc.—in fact, every thing except royalty for use of patent right, and interest on investment and wear and tear, the last two items being estimated at 20 cents per foot.

The average cost per foot for labor was.................	$1 15
" " " " " diamonds.................	66
" " " " " supplies, repairs, etc........	41

The deepest holes were found to be the cheapest per foot, eight of the number having been over 500 feet in depth, leaving out the first two for the purpose of comparison, as these two cost more than the rest by reason of being the first. The average of the deep holes per foot was $1.95, while the general average without the first two was $2.10 per foot. The diamond account proved to be a very difficult one to determine, owing to the fact that the same diamond was used over and over again in different holes, gradually depreciating until it became ground up into fine dnst, or too small to either set in the bits or core-barrels. The diamonds were bought in the quantity, the borts or real diamonds of light color costing $11 per carat, and the diamonds of dark color $9 per carat. The bits were set with these diamonds, five of each kind weighing, on an average, about 18 carats per bit. When a bit was set with new diamonds, and sent out, if it was charged to the hole using it, that hole would be paying for diamonds that would still be of use in other holes, and consequently the first holes would pay for all the diamonds. To get over this difficulty, as it was impossible to keep track of every individual diamond, it was found necessary to adopt some percentage to charge for loss. To obtain this, the weights of the diamonds in each bit, before using and after, were carefully noted, and the amount of dust or fragments obtained. This being done with several bits, the depreciation in diamonds was found to be about 22 per cent, and, to allow of some margin, it was assumed to be 25 per cent; or, in other words, that the value of the diamond was gone after being reset four times. This estimate was subsequently revised, and with the results given from the use of some 120 bits, and from an inventory of diamonds and dust on hand, it was found that 18 per cent was nearer the mark.

The costs per foot, given in the following table on the basis of 25 per cent, are therefore slightly greater than the real amounts. After the above result of 18 per cent was obtained, a percentage of 20 was assumed in subsequent work to allow of margin.

There is a pamphlet on "*Die Diamant Bohrmaschine,*" by M. Pupovac, Vienna, 1874, giving a number of results of work with the diamond-drill. Other references will be found in "Journal of the Franklin Institute," vol. xliii., "The Diamond Rock-Drill;" "Journal of the Franklin Institute," vol. lxviii., p. 353 (1874), "Diamond Drilling at Delano, Schuylkill County, Pa.," by C. E. Ronaldson; Van Nostrand's "Engineering Magazine," vol. xii., p. 44 (1875), "The Diamond Rock-Drill," with also a letter, dated May 13th, 1872, from Mr. James Brunlees, stating that the diamond-drill was being used in the heading of the "Clifton Tunnel" with good effect (this letter is addressed "To the Machine Tunneling Company); article on prospecting with the diamond-drill in the Cleveland District, Lancashire, England—"Scientific American," p. 35, July 20th, 1872 (from "The Engineer"); "Diamond Rock-Boring Company," "Engineer," February 25th, 1876, p. 139. These references are almost all descriptive of rapidity of work, etc. Mr. Riley's paper stands, so far, alone as the most thorough record we have of the cost of drilling by company work with the diamond-drill. The paucity of data on this subject is probably chiefly owing to much of the work being done by contract at fixed rates by the diamond-drill companies.

TABLE 20.

No. of Hole.	Location.	Date of Boring. Began.	Date of Boring. Completed.	No. of Drill.	Diameter of Hole.	Diameter of Core.	Length of Bore-hole. Stand Pipe.	Length of Bore-hole. Boring.	Length of Bore-hole. Total.	Progress per day, 10 h'rs. Average.	Progress per day, 10 h'rs. Maximum.	Total Cost.	Cost per Foot. Labor.	Cost per Foot. Diamonds.	Cost per Foot. Fuel, Water, Repai's, etc.	Cost per Foot. Total.	Cost per Foot. Interest	Cost per Foot. Total.	Remarks.
	Pennsylvania.				in.	in.	feet.	ft. in.	ft. in.	ft. in.	ft. in.								
1	Delano, Schuylkill County...... ...	April 14, 1874	June 11, 1874	1	2	1½	13·0	501 8	514 8	10 1	20 0	$1,998 90	$1 63	$0 97	$1 28	$3 88	$0 20	$4 08	Coarse conglomerate; had to haul water.
2	Hazleton, Luzerne County...... ..	July 1, "	Sept. 26 "	1	"	"	8·0	682 0	690 0	9 3	36 7	2,189 43	1 63	1 14	0 41	3 18	0 20	3 38	
3	Ashland, Schuylkill County........	Oct. 13, "	Nov. 6, "	1	"	"	26·3	344 4	370 7	14 8	34 0	957 19	1 41	0 79	0 38	2 58	0 20	2 78	
4	" " "	Nov. 24, "	Dec. 8, "	1	"	"	20·4	258 7	278 11	13 9	26 9	941 62	1 60	1 36	0 41	3 37	0 20	3 57	
5	Mount Carmel, Northumberland Co.	Jan. 15, 1875	Mar. 5, 1875	2	"	"	23·0	877 6	900 6	15 3	28 3	2,187 74	1 51	0 56	0 34	2 41	0 20	2 61	Preparatory shaft, deep and expensive.
6	Mahanoy City, Schuylkill County..	Dec. 30, 1874	Feb. 27, "	1	"	"	23·0	350 10	373 10	7 2	20 0	1,512 35	1 99	1 57	0 48	4 04	0 20	4 24	Delayed with frozen water-pipes.
7	Montana, Columbia County...	April 16, 1875	June 5, "	2	"	"	62·0	655 5	717 5	14 9	33 9	2,123 90	1 64	0 76	0 55	2 95	0 20	3 15	Preparatory shaft, deep and expensive.
8	Mahanoy City, Schuylkill County..	Mar. 24, "	April 7, "	1	"	"	30·9	250 10	281 7	19 3	33 7	795 00	1 25	0 94	0 63	2 82	0 20	3 02	
9	" " " " ..	June 2, "	June 9, "	1	"	"	41·0	122 11	163 11	17 6	23 4	572 10	2 29	0 49	0 73	3 51	0 20	3 71	
10	Mount Carmel, Northumberland Co.	June 28, "	Aug. 27, "	1	"	"	27·0	695 10	722 10	13 2	24 0	1,216 08	0 85	0 40	0 43	1 68	0 20	1 88	
11	Pittston, Luzerne County..........	July 1, "	July 26, "	2	"	"	1·10	462 7	464 5	21 1	42 5	699 47	0 80	0 38	0 33	1 51	0 20	1 71	
12	" " "	Aug. 5, "	Aug. 20, "	2	"	"	1·8	366 1	367 9	26 3	44 9	495 26	0 82	0 36	0 17	1 35	0 20	1 55	
13	" " "	Sept. 3, "	Sept. 7, "	2	"	"	18·0	80	98 0	20 2	25 3	205 00	1 09	0 73	0 27	2 09	0 20	2 29	
14	Hazleton, " "	" 13, "	" 17, "	1	"	"	10·0	150	160 0	30 0	58 0	245 55	0 88	0 25	0 40	1 53	0 20	1 73	
15	Pittston, " "	" 13, "	Oct. 9, "	2	"	"	1·8	509 7	511 3	21 3	33 5	501 15	0 59	0 28	0 11	0 98	0 20	1 18	Cheapest hole.
16	Hazleton, " "	" 24, "	Sept. 29, "	1	"	"	11·6	139 3	150 9	27 8	39 2	288 40	0 97	0 47	0 47	1 91	0 20	2 11	
17	" " "	Oct. 6, "	Oct. 15, "	1	"	"	16·6	126	142 6	15 9	23 8	334 69	0 97	0 71	0 59	2 27	0 20	2 47	
18	Wilkesbarre, " "	" 22, "	Nov. 27, "	2	"	"	0·0	536 3	536 3	17 3	28 5	832 19	0 78	0 45	0 32	1 55	0 20	1 75	
19	Hazleton, " "	" 27, "	Dec. 18, "	1	"	"	16·0	624 0	640 0	33 7	32 8	1,370 30	0 88	0 73	0 53	2 14	0 20	2 34	
20	Pittston, " "	Dec. 9, "	Jan. 29, 1876	2	"	"	12·5	334 9	347 2	16 8	24 0	563 12	0 94	0 50	0 18	1 62	0 20	1 82	
21	Hazleton, " "	Jan. 17, 1876	Feb. 19, "	1	"	"	7·0	478 4	482 4	16 1	33 3	1,216 17	1 12	0 89	0 52	2 53	0 20	2 73	
22	Pittston, " "	Dec. 31, 1875	Jan. 17, "	2	"	"	18·7	303 3	321 10	23 9	28 4	322 24	0 65	0 20	0 15	1 00	0 20	1 20	
23	" " "	Feb. 9, 1876	Feb. 25, "	2	"	"	27·0	350 0	377 0	26 9	29 4	396 58	0 67	0 22	0 16	1 05	0 20	1 25	
24	" " "	Mar. 3, "	Mar. 18, "	2	"	"	8·0	280 5	288 5	20 6	46 3	385 20	0 59	0 60	0 15	1 34	0 20	1 54	
	Total..................................							9901 9											
	Average..................................							.. ...	......	18·9ft.	......	... .	$1 15	$0 66	$0 41	$2 22	$0 20	$2 42	

Merits and Demerits claimed for the various Principles Employed in Drills.

There are two usual methods of working the valve—by tappets and by fluid agency. It can be said about the tappet system of working a valve, that, while giving a positive motion to the valve, there is liability to and there always has been trouble from breakage of the tappets and their slight working parts, which are struck three to six hundred times a minute with such great force. This trouble is increased in frosty weather, and this brings the repair bill up very high. Some opponents of tappets think that because the piston has to strike the tappet on the working stroke, the full force of the blow is not delivered upon the rock; but this seems only a trivial matter. Where the tappet projects from the steam-chest into the cylinder, there is required more dead space, and there is consequently more consumption of air or steam. There is, too, danger of knocking out a head in case the tappet breaks and falls into the cylinder. The fewer working and wearing parts there are, the fewer the chances of stoppage, and the less the repair bill.

In reference to automatic feed; this is not generally applied to small machines, because these being used underground, light weight and simplicity are desirable. When automatic feed is used, but one man is needed to work the machine. In many reciprocating rock-drills, the feed screw gets worn, and the cylinder jiggles back and forth upon the guide ways, pounding and breaking the screw or fastenings.

In reference to steam or air cushion, those who oppose it do so on the ground that the motive fluid must be introduced by this means in front of the advancing piston; so that, although the head is preserved from being knocked out, the blow is lessened in force and depth.

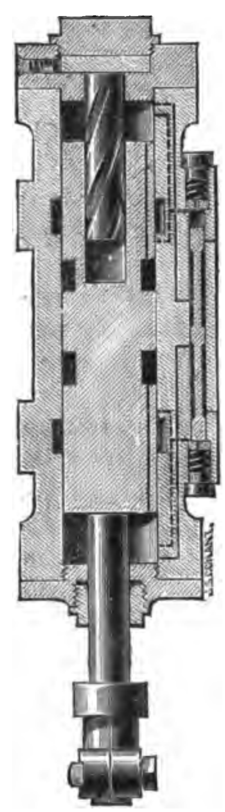
Rotary drills have claimed for them the advantages, that they give to the rock more of the driving force than do percussion drills, in which part of the force spent in striking the blow is given back to the machine. Rotary drills should be exempt from all troubles arising from crystallization of iron and steel parts.

In some cases friction drills take a great quantity of water to wash out the drill hole—this water in many instances requiring force to put it where it is wanted, and if in large quantities, giving trouble again in deep mines. The water consumed by the drill may in some cases be ejected in fine spray, serving to absorb in some measure the powder smoke, so that the face shall be workable in a few minutes after the blast.

By employing a lateral arm clamped to the column, the drill may be moved in or out on the arm, and the arm moved up or down or moved around, thus commanding a large portion of the breast without moving the column. The column should thrust against short pieces of timber at top and bottom. Columns over 8 feet long are apt to give trouble from vibration. For very large work, as tunnels, the column may be used to work out a drift of considerable size in extension of the line of the roof, and tripods used to take up the bottom. This has the advantage of dividing the drilling ground and enabling more men to be used. The disadvantage of the carriage is that the ground must be cleared before the carriage can be run up to the heading.

The principal percussion rock-drills employing steam or compressed air, in use in the United States, are, named in alphabetical order, the Bryer (Newhall) Burleigh, Ingersoll (Sergeant), Johnson (Duncan), Rand, and Wood. The Pennsylvania Diamond Drill is about the only American type of rotating core-extracting drills.

The cut below represents a sectional view of the Bryer drill. To the left hand, midway between the centre and either end of the cylinder, are two annular grooves connected on the back by a passage-way, joining the steam chest. The exhaust port is located in the centre of the cylinder. In the piston head are two grooves, which also pass entirely around it. In the right hand portion of the piston, extending from the grooves in the same to either end, is shown a passage-way for steam.



BRYER DRILL.

On the extreme right hand of the cut is the cushion valve, its lower end resting upon the lower head of the valve chamber. The valve is cylindrical, and reduced in size between the ends and middle, to admit the free passage of steam to the exhaust port of the cylinder.

The second cut represents the Bryer drill mounted upon a column as used in mines. It is claimed to work expansively in part. The merits urged by the makers are lightness, simplicity, durability, and economy of motive fluid.

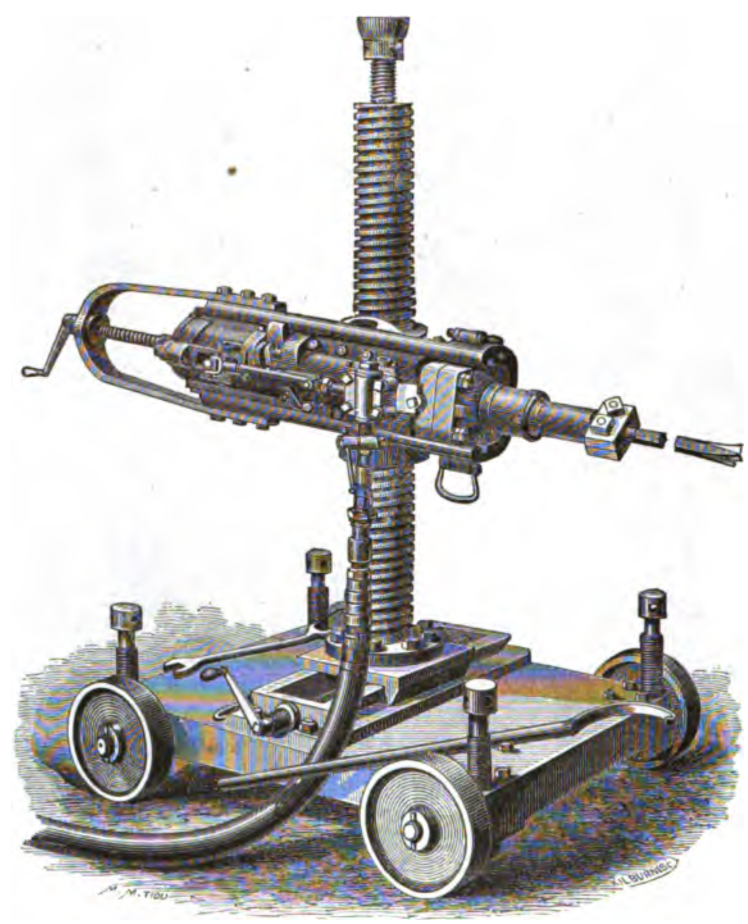
BRYER STOPING DRILL IN OPERATION.

PARTICULARS OF THE BRYER ROCK-DRILL.

No.	Diameter of Cylinder.	Length of Stroke.	Length of Feed.	Depth of Hole Machine will bore.	Diameter of Hole.	Weight of Machine.	Weight of Tripod.	Weight of Column 6 feet in Length.	Length of Machine over all.
1	$4\frac{7}{8}$ inches.	$5\frac{1}{2}$ inches.	30 inches.	50 feet.	$3\frac{1}{2}$ to 4 in.	400 lbs.	....	....	40 inches.
2	$4\frac{3}{8}$ "	$5\frac{1}{2}$ "	28 "	40 "	3 to $3\frac{1}{2}$ "	300 "	....	....	36 "
3	$3\frac{7}{8}$ "	$5\frac{1}{2}$ "	26 "	30 "	$2\frac{1}{2}$ to 3 "	175 "	135 lbs.	200 lbs.	33 "
4	$3\frac{1}{4}$ "	5 "	24 "	30 "	2 to $2\frac{1}{2}$ "	105 "	110 "	150 "	30 "
5	$2\frac{5}{8}$ "	4 "	20 "	20 "	$1\frac{1}{2}$ to 2 "	65 "	85 "	150 "	25 "

In the Burleigh tappet drill there is a trough with ways on each side, in which the cylinder slides. The screw feed is automatic. The piston rod, which has a double annular cam and spiral grooves, controls the valve, effects the feed, and causes bit rotation. It is sometimes mounted in gangs in a frame or carriage, two on a horizontal bar across the top and two at the bottom, each having adjustability in these planes.

The single drill is mounted on a threaded telescopic iron column, having a single sharp point at the bottom and an iron thrust claw at the top. This column may also be used horizontally for shaft work.



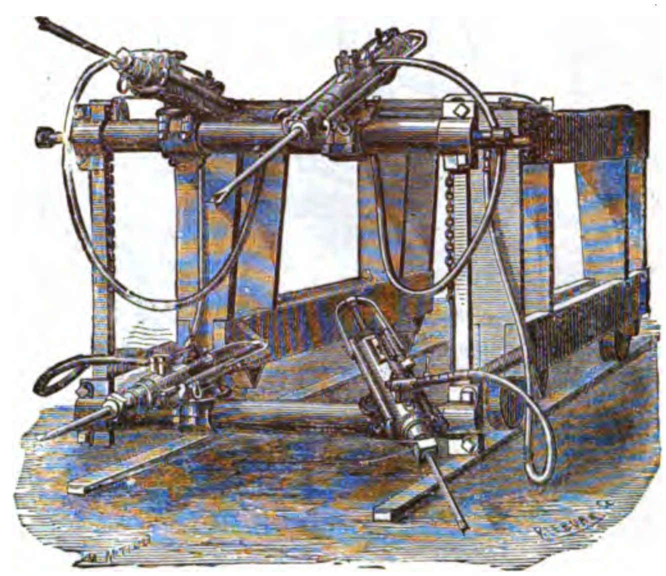
BURLEIGH MINING DRILL ON MINING CARRIAGE.

The mining drill on mining carriage has adjustment in all directions. It is intended for tunnels 6 ′ x 6 ′ to 8 ′ x 10 ′.

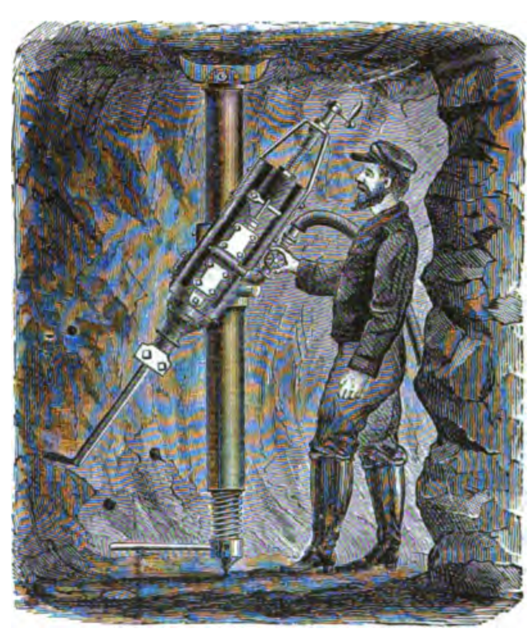
Fig. *G*, page 237, shows the Burleigh carriage for mounting four drills on two bars, the lower of which may be raised and lowered by chains, pulleys, and windlass. It is designed for railroad and other large tunnels. There is an open space 4 to 16 feet in the clear between the sides. After a blast the track is cleared by throwing the rock into the centre, and then the latter may be removed by small narrow gauge cars on a track inside the drill-carriage track. We do not know of any of these now in use, except in the Sutro Tunnel. It

may be jacked up from the track during drilling, and is held in place by screws from the ends of the upper bar, or else from the frame to the tunnel roof.

For tunnels 6 ′ x 6 ′ to 8 ′ x 12 ′ the tunnel carriage shown on page 237 is designed. It has a drill-holding bar on long arms, controlled by chains and windlass for vertical adjustment. The bar has jack-screws at its ends, to jam the whole in place.

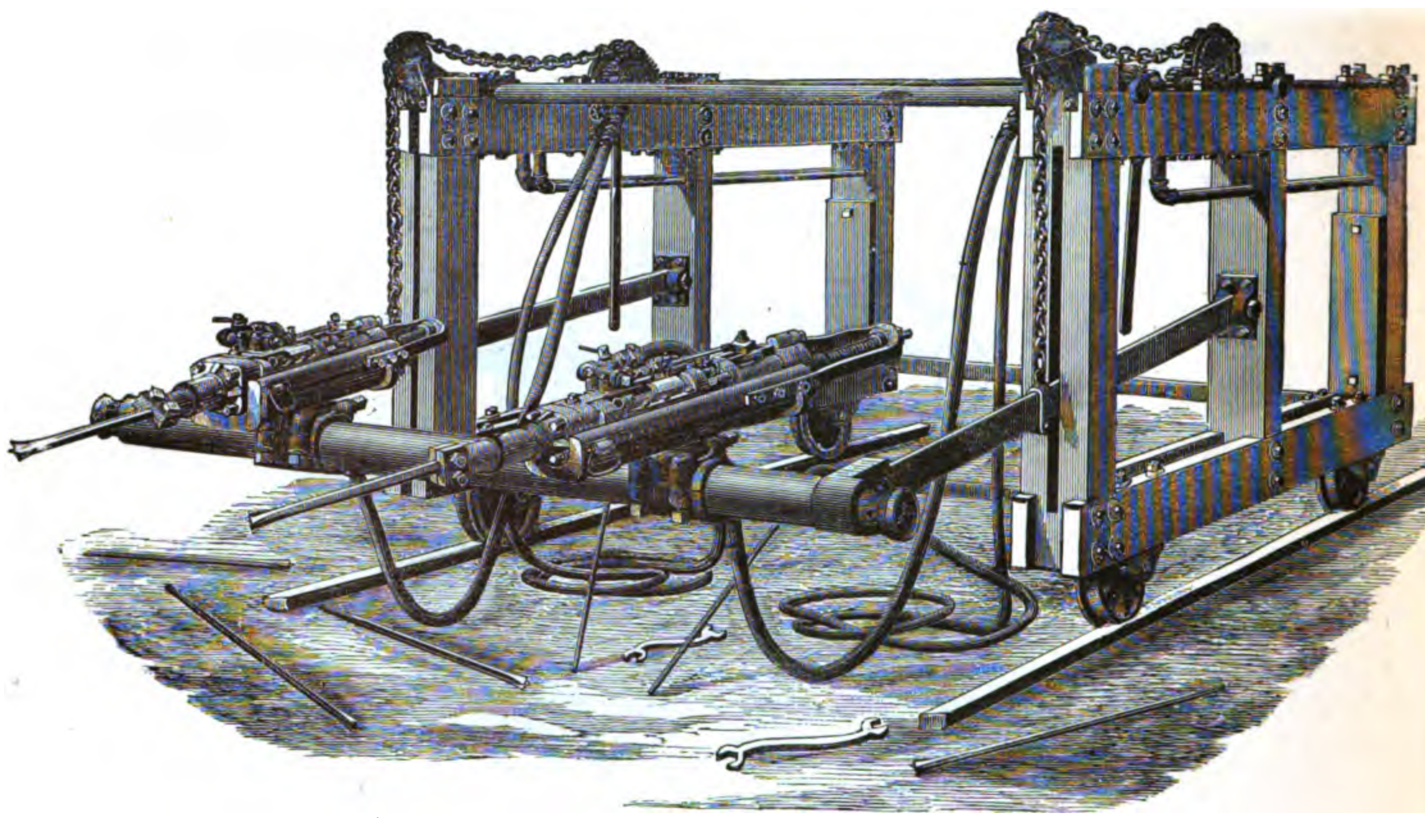


BURLEIGH TUNNEL CARRIAGE MOUNTING FOUR DRILLS.

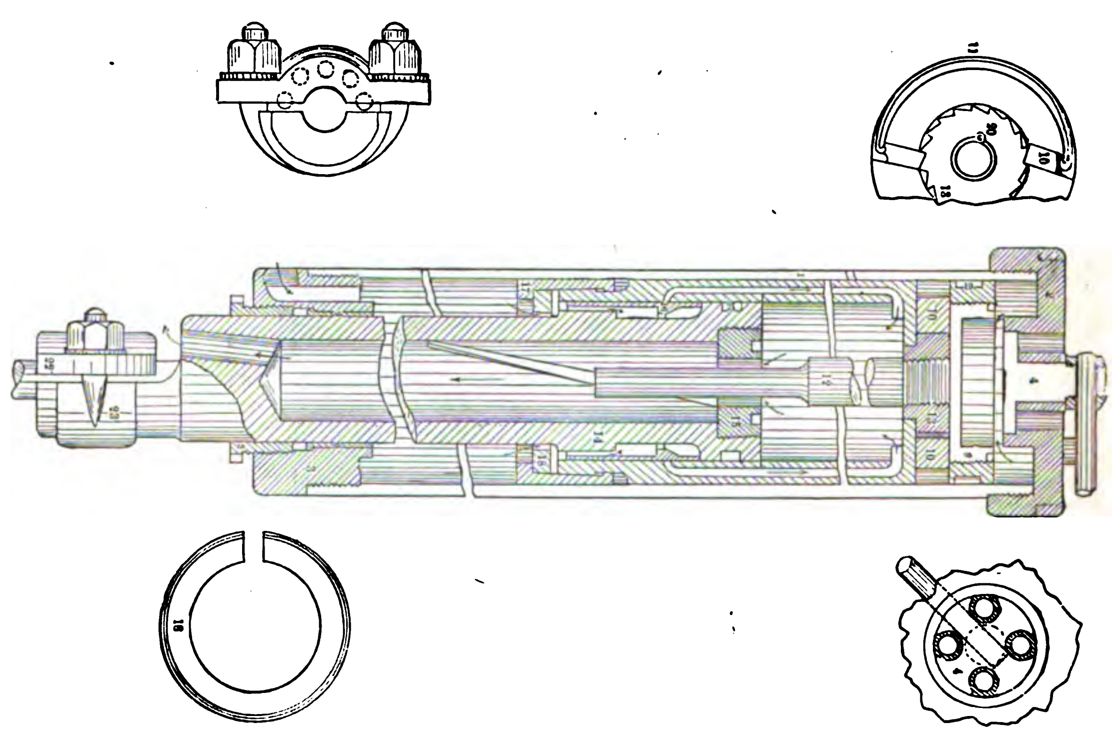


BURLEIGH STOPING DRILL ON STOPING COLUMN.

The Burleigh Rock-Drill Company says that its stoper drill described above, will at 65 pounds pressure move along the floor a granite block of 6 or 7 tons. The piston



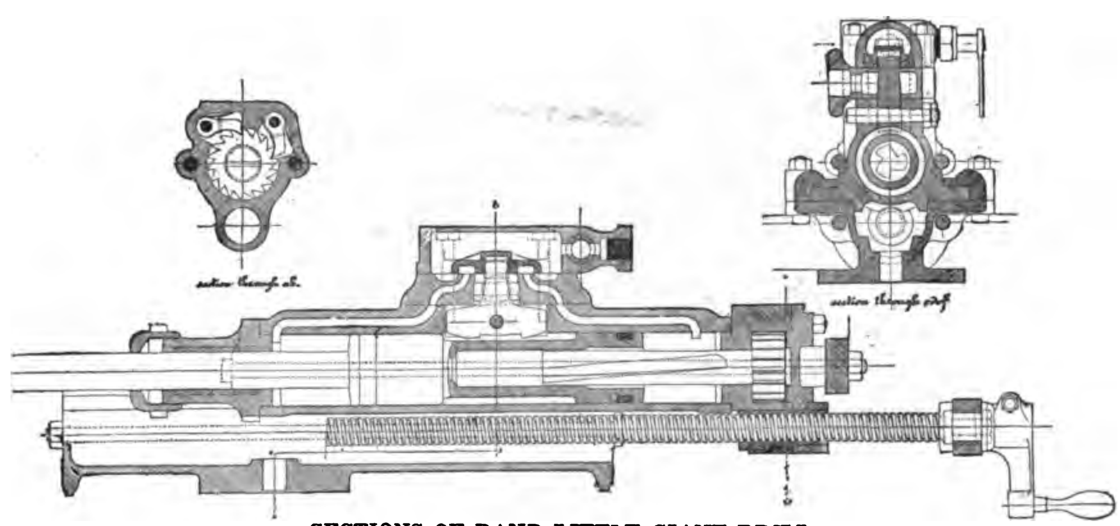
BURLEIGH TUNNEL CARRIAGE FOR MOUNTING TWO DRILLS.



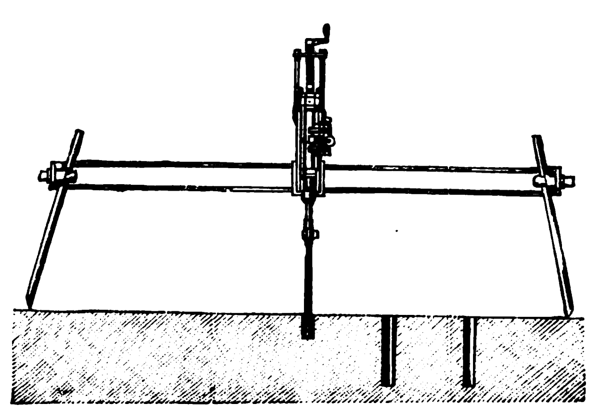
SECTION OF JOHNSON (DUNCAN) ROCK DRILL.

weighs about 56 pounds when working with drill point; has 6 inch stroke and makes 350 strokes with 65 pounds steam.

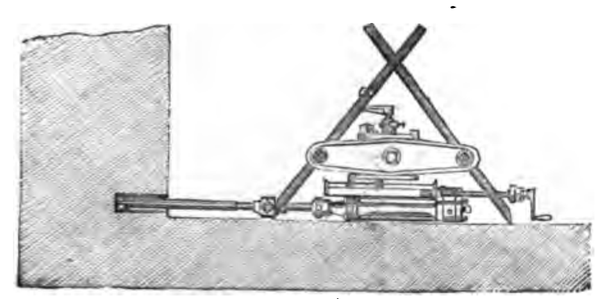
The Johnson (Duncan) rock-drill has self feed, and steam or air pull back on the drill-point from the rock. The machines are mounted in two cylindrical clamps to give universal motion, upon the column or a tripod. The idea of this is to enable the machines to be slipped through the body clamped to or from the rock, thus adding to the length of the feed. The tripod has independent movable and extensible legs with sharp feet and slides, to enable the whole to be put near the walls or corners.



SECTIONS OF RAND LITTLE GIANT DRILL.



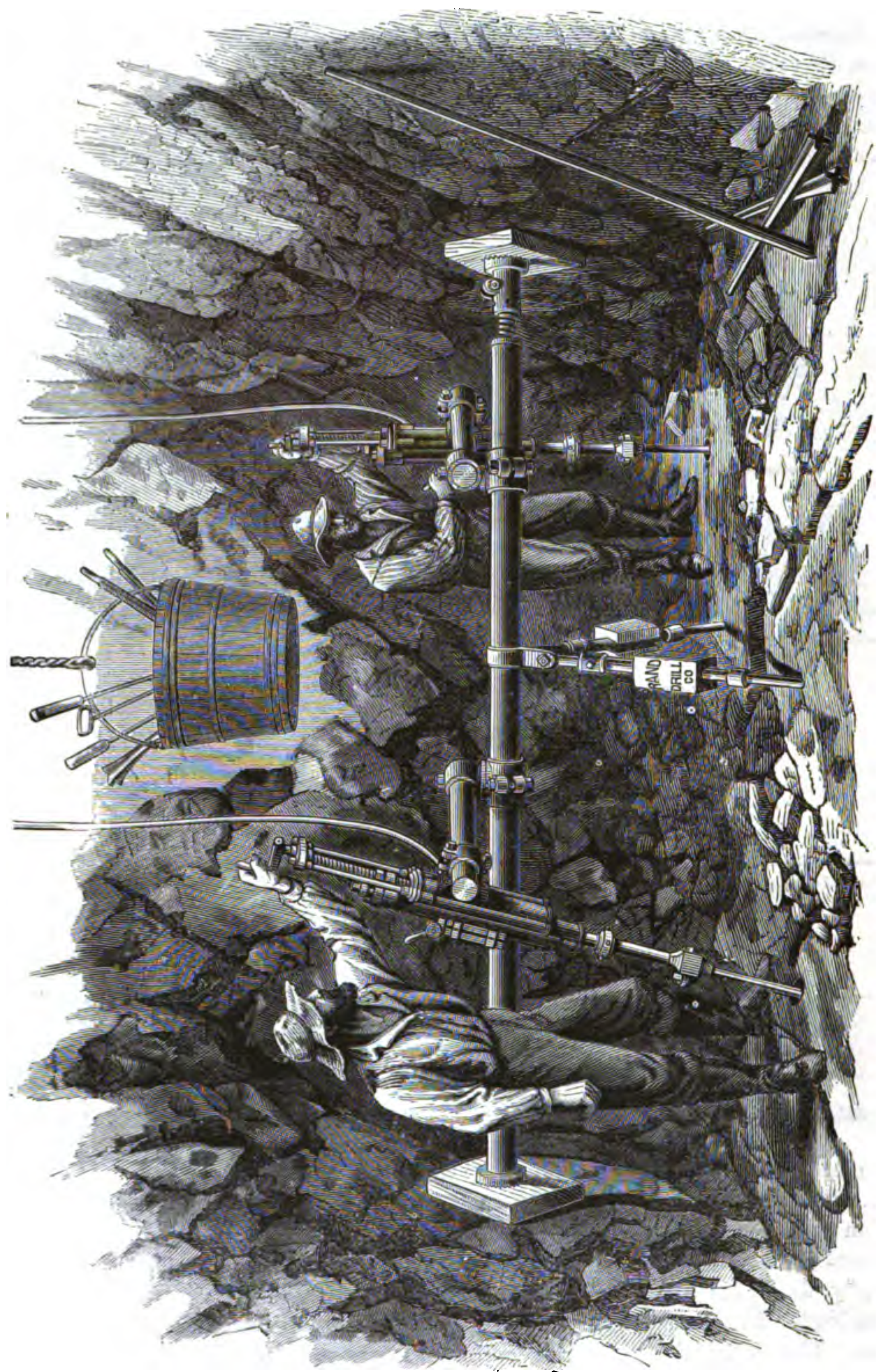
RAND DRILL AS A VERTICAL GADDER.



RAND DRILL FOR HORIZONTAL GADDING.

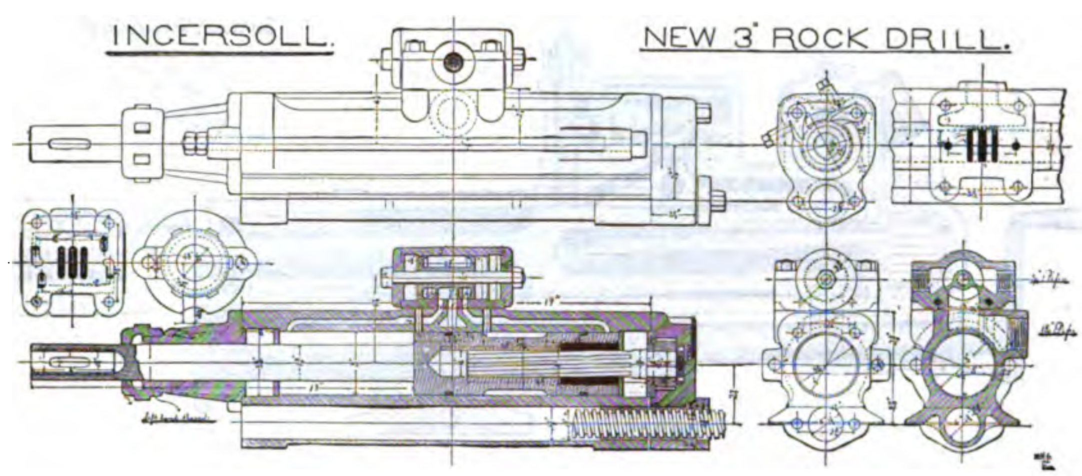
In the Rand drill the tappets are moved by the piston instead of by projections upon the piston rod. The feed in the machine is by hand, a square-threaded screw carrying the cylinder along on its bed-plate, which latter has a vertical pivot.

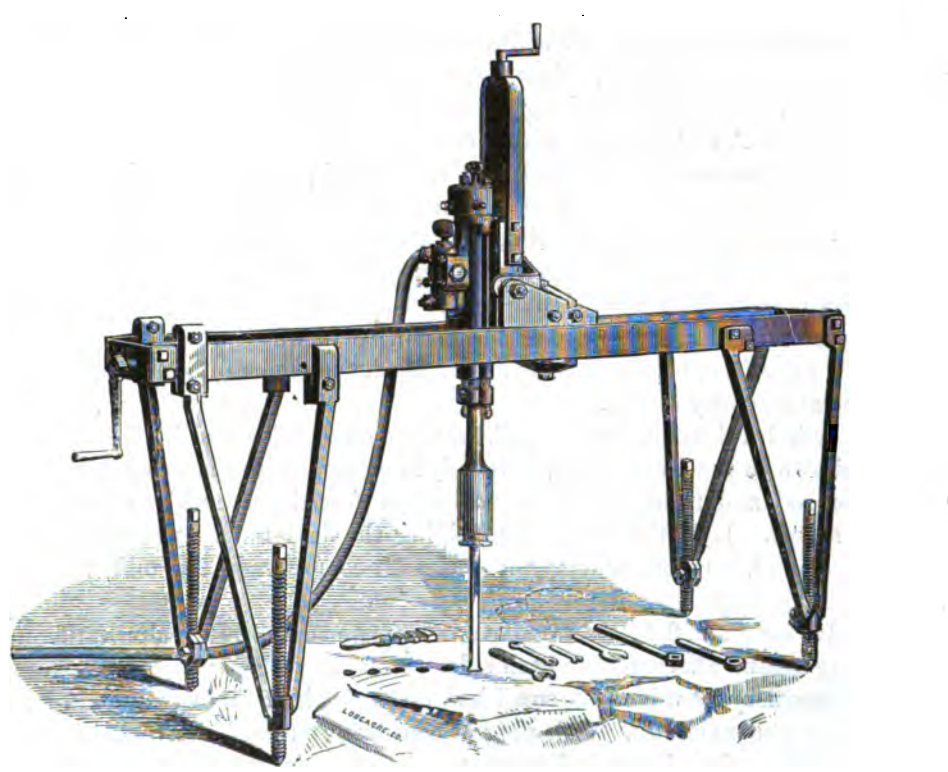
The new Sergeant drill, made by the Ingersoll Rock-Drill Co., was described at length, and illustrated, by Mr. F. L. Miller, C. E., in a paper before the Engineers' Club of Philadelphia, September, 1880. The accompanying cut on page 241 shows the working drawings of the latest form. The principal peculiarities are in the valves and the ports and passages. The valve is a cylinder, having flanges somewhat smaller than the cylindrical steam chest, in which the valve slides upon a central bolt, which serves to hold the chest heads together. The chest



SINKING A SHAFT—USING COLUMNS.

heads have rubber cushions. The piston is of great length, and has a cavity as long as the piston stroke, so that it will always register with the ports and allow the steam exhaust from the valve to be exhausted therein. We will suppose the valve at one end of the stroke and steam let into the chest; the steam will pass to the cavity between the flanges; the steam



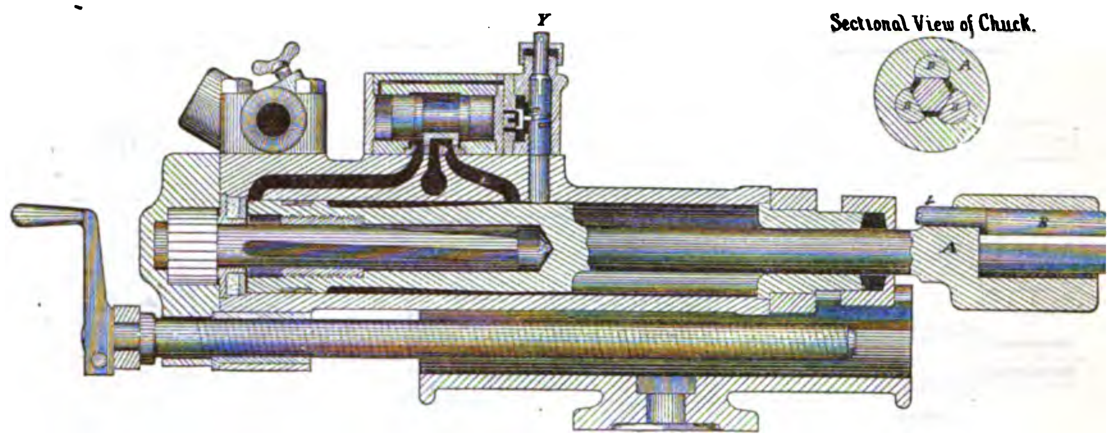


WOOD'S IMPROVED DRILL AND CHANNELING FRAME.

being exhausted at the other end there will be no opposition to the valve moving toward that end, by reason of the steam rushing past the flange nearest the cylinder valve end. The cavity in the main piston prevents the valve being shifted until the main piston is nearly at the end

of its stroke, when it will uncover the exhaust port of the valve cylinder in which the steam is confined, the steam passing into the upper port, then to the opposite end of the chest, then by the lower port to the cavity in the piston. Rotation is by fluted bar and nut, and feed by hand.

THE DYNAMIC ROCK DRILL.



The Improved Wood Rock-Drill, as developed and manufactured by the Graydon & Denton M'f'g Co., of Jersey City, N. J., is known as the "Dynamic."

The cylinder is compact, and slides in guides in a shell, through which a single bolt passes to secure it to the tripod, column, or other mounting.

The motion of the cylinder along these guides is controlled by a screw turning in a yoke attached to the shell, and working with a crank.

The piston, piston-rod, and chuck are in one solid piece, the chuck *A* being larger than the piston, a feature which we believe is peculiar to this drill.

The front head is formed by shrinking a wrought iron ring around two semi-cylindrical pieces, thus holding them firmly together about the piston rod.

Rotation is secured by a rifled bar free to turn in one direction only, and working in a brass nut screwed into the back end of the piston head, which is correspondingly rifled.

Owing to the form of the front cylinder head, the chuck *A* may be as large as desired, and is made abundantly strong.

Three cylindrical wedges, or gibs, *B*, flattened on one side, and having eccentric prolongations *b*, as shown in the illustrations, fit loosely in corresponding grooves in the chuck inclined to the piston rod, and firmly grasp the steel when forced forward by the momentum of the first blows struck. It is this device for holding the drill rod that is claimed to enable this drill to take round, octagon, or hexagon steel as it comes from the mill, without having the shanks turned or forged.

The valve is a plain, flat slide, fitted to a valve piston, having its reciprocating motion caused by admitting steam alternately to each side, through passages which are opened and closed by a small auxiliary *D* valve. A small hub on the back of this valve fits in a helical groove in the vertical plug as shown. This plug is constantly pressed downward by steam pressure upon it, but is forced up by an incline upon the piston, during the return stroke. The throw of the auxiliary valve is thus accomplished with a minimum of shock, and as the valve piston is moved by steam and cushions on steam, it also operates with little or no shock; and the only part subjected to serious wear is the plug which rides upon the piston.

The stem or adjuster *Y*, enables the plug to be turned on its axis, and the auxiliary valve to be raised or lowered in the helix.

By thus changing the setting of the auxiliary valve, the stroke of the piston may be varied at will, or may be confined to any part of the cylinder.

The drills are mounted on stands suitable for each class of work to be done; as tripod, column, quarry frames, and carriages.

ABSTRACTS OF PAPERS ON AND DESCRIPTIONS OF ROCK-DRILLS.

[Abstract of article on rock boring machinery in the "Scientific American Supplement" Sept. 9, 1878. Page 2,221. From pamphlet, "The Application of Machine Power in Rock Drilling," by Richard Schram, London. G. Hill, Westminster Bridge Road.]

Schram's classification of rock-drills is into five classes:

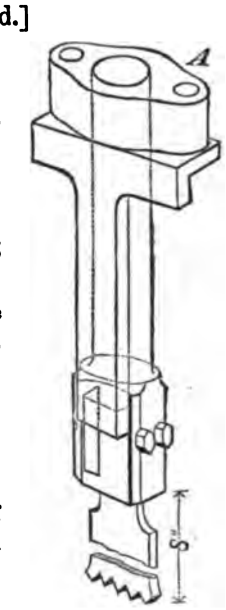
1st. Ram system—Schwartzkopff and Warsop.

2d. Lever system—Schumann, Burleigh, Sach, Mackean, Warrington, Ingersoll, Drum, Roanhead, Cranston, Barrow, and many others.

3d. Duplex—Sommeiller and Ferroux.

4th. Rotary "diamond"—Brandt, etc.

5th. Direct acting—Darlington, Schram, and Reynolds, without slide; and Osterkamp, Schram, Cederblom, and others, with slides.



WOOD'S GADDER.

The ram system Schram considers impracticable. In the lever are great wear and tear and loss of power. The duplex system requires cheap and plentiful compressed air, and the great length of the machine necessitates all the borings being nearly horizontal. Lisbeth's rotary hand drill, as improved by Macdermott, works well in coal and soft slate, but not in hard rock. Among direct acting machines with slides are Osterkamp's, Doering's, Schram's, Cederblom's, and others. In Schram's the only moving parts are the main piston, slide piston, and slide, and the rotating portion with its piston.

The slide rod is in the front of a double spindle valve, so as to remain in position without any recoil until the piston has made the greater part of its stroke. To prevent the drill sticking fast, there is a reverse rod to reverse the slide and pull the drill out. To prevent the piston striking the lower cylinder cover, there is an air cushion at the lower end of the cylinder, and there is also an iron ring and an India rubber washer (exchanged for one of iron when steam is used), to moderate the violence of the shock such blows would cause. To rotate the drill on the back stroke, there is a twisted bar with a grooved disc, on a brake acted upon by a small piston.

[Abstract of paper in *Scientific American Supplement*, December 22, 1877, page 1634, taken from *Miners' Journal*.] The principal shapes of drills are + × N and T. The edge of the second tool should not be wider than that of the first one; it is better that the drills should decrease in diameter, say by $\frac{1}{16}$ to $\frac{1}{8}$ inch, thus, $1\frac{1}{4}$, $1\frac{1}{8}$, 1, etc. If a hole 12 inches deep and 1 inch diameter take 4 minutes to drill, one 2 inches in diameter, of the same depth, with the same machine, should take 16 minutes. That is, the time and power to bore vary with the square of the diameter of the hole. It is then best to have the short hole of small diameter.

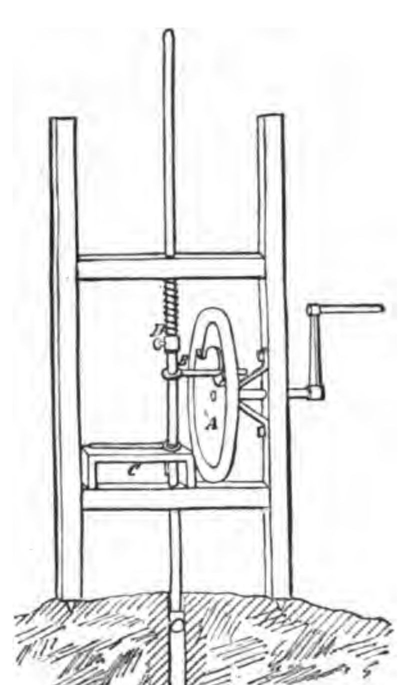
Tunnel or Mine.	Machine Employed.	Machines working together.	Machine in reserve for one in use.	Air Pressure per sq. in. pounds.	Form of Tool Employed.
Mont Cenis	Sommeiller	10	7	9	Z
St. Gothard	Ferroux, Dubois & Francois, McKean	6	68	90	×
Musconetcong	Ingersoll	6	....	60 to 70	×
Morstet	Beaumont	2	....	50	Circular.
Cronbran	McKean	2	1	70 to 80	Flat Tool.
Port Skewet	Grach	2	2	60	×
Saarbruck	Sach	....	6	60	Flat Tool.
Bonchamp	Dubois & Francois	4	1	67	× + Z
Blanzy	Darlington	4	None.	45	Flat.
Tuniera	"	½	"	50	"
Blokokish	"	½	"	45	"

The Stow Flexible Shaft has not been used much for mining work. At the present writing (April 1, 1881), there are some parties experimenting with the shaft for drilling blasting holes for coal cutting. One improvement in the Stow shaft is dated March 12, 1878, covering a roundabout transfer to carry power by means of driving belts. This patent consists in the combination of a driving pulley on the line or counter-shaft, a weight carrying two or more pulleys, the swivel frame carrying two or more pulleys, a pulley on the operating tool, and a driving cord, whereby the tool may be extended two or more times as far as the weight is raised.

A Submarine Rock-Drill by Edward Mone, of Portland, Maine, is illustrated in the *Scientific American Supplement*, January 27, 1877. This is a rotating apparatus, with a drill shaft bearing a bevel pinion, driven by a bevel wheel upon the shaft of a rotary engine driven by steam or compressed air, obtained by flexible pipes from the boat above. The drill is withdrawn by reversing the engine, and the whole affair is highly impracticable.

Shaw and Clark's Rock-borer (*Scientific American Supplement*, November 10, 1877, page 1538), consists of a cylinder and piston rod with two pistons. Steam or air is introduced in the middle between the two pistons, and acting upon one or the other of the pistons, closes the exhaust, and forces the air from one piston to the other, by one or the other piston coming in contact with the slide valve, closing and opening suitable ports. The feed is automatic, by means of an auxiliary cylinder.

The Jordan Hand Power Drill, shown in the *Engineer*, November 30, 1877, page 394, has a tubular rod of steel working through glands at the top and bottom cylinder, the top gland being packed with cap leather, and the piston slightly cupped on its upper surface, and packed with the thin disc of leather, which, when pressed down by the nut, becomes a cup packing. The top of the tubular packing has a lifting block in three parts, two forming the body, and one the sleeve by which all are held together; there is a driving nut, the lower end of which revolves on the piston as in a dressed bearing. This nut is screwed through its entire length of eight inches to fit the screw portion of the steel drill bar, which passes through the centre of the machine and carries the boring tool at its lower end. The drill bar is screwed through one half of its length, and the other half is hexagonal, and passes through the cap like that at the lower end of the tubular piston rod, so that it must turn with the piston, while having independent lengthwise motion through its centre. There are two cams on the wheel shaft to govern motion of the drill rod. In the lower portion of the cylinder, the air enters through holes, and in the upward stroke of the piston is compressed enough to cause the down stroke to be made rapidly, as soon as the cam has passed the collars. The revolving motion of the bar is got by frictional contact of the cam against the revolving collar; this friction being regulated by a thumb screw upon the feed wheel. Two men work this machine, making 140 to 180 strokes per minute; the speed claimed being 6 inches per minute, of 1¼ or 1½ inch holes, in Portland stone, and 3 inches per minute of 1¼ inch hole in Aberdeen granite. The mining machine is claimed to work a 1½ inch hole, 1½ to 1¾ inches per minute in Aberdeen granite.



MERSHON'S HAND DRILL.

The Jordan drill was made by the Hand Power Drill Co., Queen Victoria Street, London.

Mershon's Hand Drill is illustrated in the *Scientific American*, June 9, 1877, page 358. There is a strong frame through boxes in the cross

beams on which the drill slides. One end of a short shaft is journaled into the frame, and the other end brackets. The inner end of the shaft bears a disc A, with an arc-shaped slot, in which there is journaled a roller concave in the direction of its length. There is an arm B projecting from a ring encircling the drill and passing through the slot in the disc A, there is a block C fastened to the cross beam to receive the ring of the arm B at the lower portion of the stroke. The drill is enlarged and V-shaped, so as to trim the edges of the hole. There is a spiral spring around the drill, compressed by a fixed collar D on the drill bar. Inventor, A. J. Mershon, Warsaw, Ind.

Frolich's Rock-Drill [*Engineer*, September 8, 1878, page 321].—In this machine the slide valve is fitted into a piston. Each end of the cylinder into which this piston fits, is connected by a passage with the main cylinder, and the ports in which these passages terminate are alternately uncovered by the main piston when traveling either one way or the other. In starting, the compressed air enters through one of the main ports into one end of the main cylinder, driving the main piston forward until one of the ports corresponding with the valve cylinder is exposed to it. The valve piston having got pressure on one side will throw the main valve the other way, thus opening the main port on the other side and causing the reverse stroke of the main piston. In each end of the valve cylinder is a vent, through which the air exhausts. The size of this opening controls the speed at which the main piston moves. The rotary motion during the return stroke is given by a rifled bar. This is prevented in turning up the head with a ratchet like teeth, facing the toothed disc, with stops which prevent it from turning. On the end disc is a plunger fitted into a small cylinder to which the compressed air is constantly admitted by the passage, while the disc and the head of the rifled bar are in a chamber, and have free connection with the rear end of the main cylinder. The feed motion is automatic, by means of the screw and nut, the nut being free to turn and provided with ratchet teeth, engage two driving balls fixed on the lever, receive motion from the piston L in a cross cylinder receiving air from main cylinder. This air is governed by means of grooves in main piston rod, corresponding with grooves in the cylinder permit air to escape in a channel. Grooves in the main piston rod permit the escape of air from the small cylinder. When the main piston gets near the end of the return stroke, the small piston returns, by reason of the smaller area around its piston rod being continually exposed to the pressure of the compressed air from the passage. The screw serves to alter the stroke of the small piston. In this machine there is but one lever, and no springs. In Germany a machine with $2\frac{1}{2}$ inch cylinder bored $1\frac{1}{2}$ holes in granite at the rate of 15 inches per minute, and in sandstone 18 to 20 inches per minute.

The author is indebted to Mr. George J. Specht, engineer of the Sutro Tunnel, for a description of the Brandt drill, as used in Europe. See foot-note.*

* The Brandt drill is spoken of by many German engineers as possessing qualities which should insure for it a favorable reception.

Its distinctive feature is the use of hydraulic power for forcing a toothed steel boring tool and tube against the rock, and for simultaneously rotating the bit. The waste water passing from the engine, which rotates the boring tool, is used for keeping the cutting edges of the drill constantly cool, and for washing out the drill-hole. A column for the drill is formed by a species of hydraulic jack consisting of a hydraulic cylinder and a piston forced against the sides of the tunnel, drift or shaft.

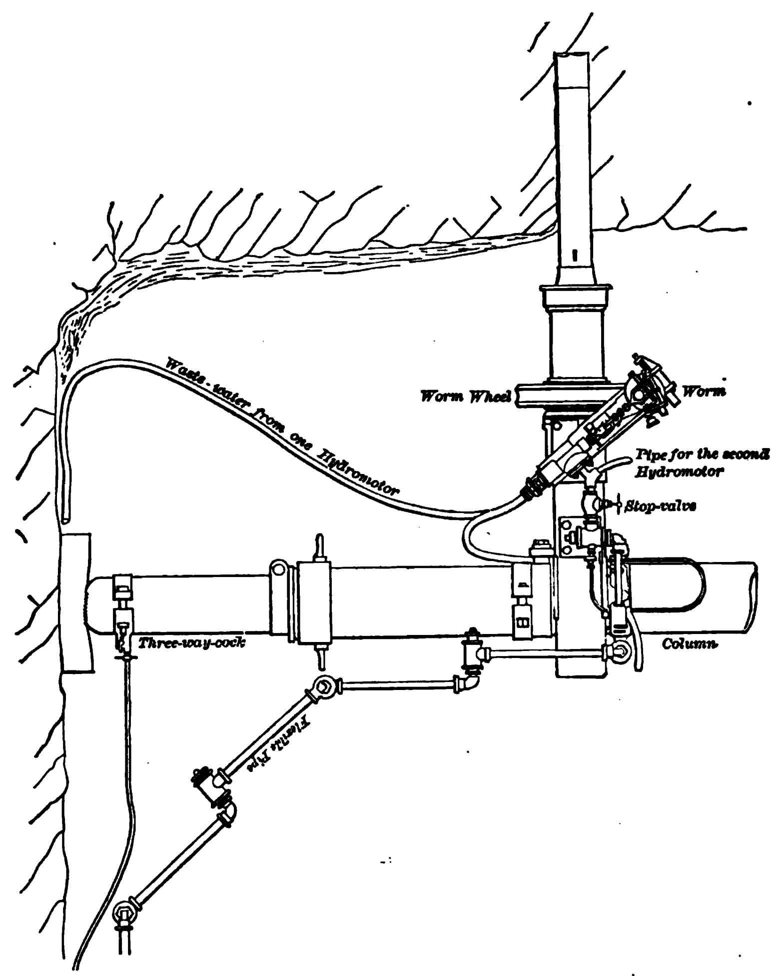
The boring tool consists of an annular steel ring provided with a series of hardened cutting teeth. The drill-bit is screwed on the drill-bar, which is tubular and consists of a series of pipes connected with one another in any suitable manner. The number of sections used depends upon the depth of the drill hole, which may be very great, as the drilling tool has only to withstand the action of torsion. The drill makes only 5 to 8 revolutions a minute, but is forced with very high pressure against the rock. This shows that the principle of the Brandt drill is entirely different from that of the diamond drill, which works with low pressure, and at a great speed (400 to 600 revolutions per minute). The Brandt drill does not pulverize the rock by grinding a hard substance on it, as the diamond drill does, but it crushes the rock and gains headway more as a circular saw in wood does. The inside diameter of

Dynamics of the Rock-drill.

As regards practice in reference to lap and lead of valve in rock-drills, and of the expansion of the motor, one of the earliest manufacturers of rock-drills (Prof. Wood), says that he

the drill-bit is 3½ inches, and may advantageously be increased to 4 inches. Experience has taught that the core of rock which remains inside of the drill breaks up into pieces about 1 inch in height, so that in lengthening the drill-rod, they can be taken out. In soft rock the core is broken up into small pieces, while in hard granite one drill makes 3 to 10 of hole, after which it has to be exchanged for a new one.

The pressure works directly against drill head, on which the drill is fastened, the working principle being that



BRANDT DRILL, AS USED ON THE SONNSTEIN TUNNEL.—Scale 1.10.

of a differential piston, with a working pressure of 942 lbs. per sq. inch; the total pressure acting on the drill is equal to 11,500 lbs. The rotation of the boring tool is brought about by a pair of hydraulic engines coupled together by a double crank shaft carrying a worm, which meshes with a worm-wheel mounted upon the cylinder. The worm makes about 180 to 220 and a maximum of 300 revolutions per minute. The amount of water actually used is equal to 75 gallons per one hour drilling. It may be thought that the loss of power by friction between worm and worm-wheel would be very great, theoretical calculation leading to an estimated loss of power of 30%; the inventor however, claims that experience has shown this to be entirely wrong. As the wheel is of gun metal, and the worm of steel, carefully hardened, the surfaces touching each other are said to acquire rapidly a high degree of polish, so that hardly any grinding or wearing off can be noticed, nor does any heating of the parts take place. Experience

has never even designed to secure expansion in the motor, whether for steam or for air. Even if it could be obtained without complicating the mechanism, he does not think the result

has shown that the loss of power in this part of the machine is at the most 15%. Taking into consideration the resistances from all other sources, it is claimed that 70% of the total power is utilized. As the worm-wheel has 38 teeth, and the power is equally distributed over the 5 teeth of the drill, we have the enormous power of 127,000 lbs. with which each tooth cuts the rock.

The drill is mounted on a hollow column, whose piston is forced by hydraulic pressure against the sides or roof and bottom of tunnel or mine. The working principle is also that of the differential piston. Assuming the working pressure to be 942 lbs., the column is forced with a pressure of 28,600 lbs. against the rock. The cylinder of the column is made of wrought iron, the piston of cast iron.

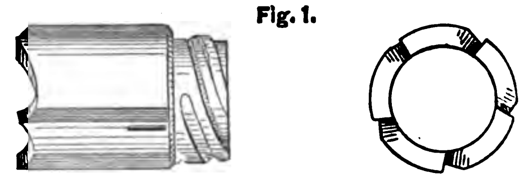


Fig. 1.

The weight of the column when filled with water is equal to 308 lbs., that of the drill proper 264.

The motive power is obtained either by the fall of the body of water directly or by means of any suitable hydraulic pressure engine or pump, in connection with an accumulator. The engine for driving the pumps for one drill should be equal to 15 horse power, and for two drills equal to 33.5 to 45 horse power. The pipes carrying the water from the pumps to the drills are of wrought iron, and have a diameter from 2 to 1½ to 0.98 inch.

Practical Results of the Brandt Rock-Drill.

The Brandt rock-drill was first tried in the Pfaffensprung tunnel of the Gotthard R. R., and was then applied in the Sonnstein tunnel, where special circumstances called for an exceptionally rapid rate of advance. The following data show the practical results of the Sonnstein tunnel in Austria :

Character of rock : very hard dolomite.
Cross section of tunnel heading : 70 sq. feet, or 7' x 10'.
Number of holes required for one round : 3, 4, or 5.
Charge of powder for one hole : 65.9 lb.
Each drill required one machinist and one or two helpers.
One hole of 12.5 feet length was drilled in 2 h. 30 min.
" 15.8 " " " 4 h.
Average progress with one machine was 6 feet per 24 hours.

In soft rock the machine worked entirely noiseless ; in hard rock only a crushing noise can be heard. No vibration of the machine is perceptible unless a person touches it with the hand.

After the whole set of holes was blasted, only a little of the rock was removed to make room for the column and to commence drilling anew, the bulk of the débris being removed by another shift.

The average time of drilling a round of holes was three hours ; four attacks were made in 24 hours.

No repairs of any magnitude were necessary.

The four machines used (2 at work, 2 in reserve), were in good working order after the tunnel was completed, just as well as when they were first put to use. The total work amounted to 950 feet of heading.

This was the first extensive trial the Brandt drill had. The above results, therefore, must be considered to be those of a new machine in the hands of comparatively inexperienced men.

Soon afterward the Brandt drill was employed in many mines in Austria and Germany ; among others, in the colliery in Altona, in Istria, where it superseded the Darlington drill.

A most decided victory for the Brandt drill was won at an extensive and very fair trial, at the Pfaffensprung tunnel of the Gotthard R. R. Circumstances had prevented the Brandt drill from finding the due recognition of its merits at the Gotthard R. R., and a percussion drill (Frohlich system) was preferred to do the work there. But as the Brandt drill won one victory after the other, and all the more prominent underground enterprises availed themselves of this ingenious invention, the administration of the Gotthard R. R. finally concluded to give the drill a trial. The Frohlich drill was used in the top-heading, and the Brandt drill in the bottom-heading of the Pfaffensprung tunnel, both working in the same kind of rock. The result of the trials was the final acceptance of the Brandt drill. The cost of one foot progress was, with the Frohlich drill, $13.20; with the Brandt drill, $7.62. There have been few fuller trials made between two different rock-drills, and the victory in favor of the Brandt drill on this occasion appears to have been a marked one. The following are a few data of this trial, all referring to the Brandt drill:

3 attacks were made in 24 hours.
Rock : hard granite.
Diameter of drill-holes : 3 inches.

desirable. The blows would not be so efficient as though the motor followed at full pressure, and the rapidity of the blows would be diminished; the diameter of the cylinder and the length of the stroke being the same. It may be claimed that the motor will be used more economically by expansion, but even if it is, it does not follow that it is desirable. The object of the drill is to make holes the most economically, all things being considered. If saving one half the motive fluid requires double the time to drill a hole, the cost of the hole may be greatly increased. The cost of the motor is only one of the many items which enter into the cost of making a hole. This builder makes the lap of the valve barely sufficient to cover the ports. The lead of the valve, he continues, is an uncertain thing in a rock-drill. In the tappet valves, so called, the valve is necessarily reversed before the blow is struck. In his earliest machines, including those made by Prof. Robinson and himself, illustrated page 208 of this work, the endeavor was to keep the motor at full pressure behind the piston until the blow was struck, after which the valve was reversed. This secured a dead blow, and was thought to be exceedingly desirable. Prof. Wood carried this to such an extreme in some later experimental machines, that there was a perceptible time between the striking of the blow and the beginning of the back stroke. The blow was perfectly dead. But then the customer objected to the machine because the blow was so dead, being, as he remarked, too severe on both the tool and the machine. At once the valve was so adjusted as to admit steam into the forward end of the cylinder before the blow was struck, producing a cushioned blow. The blows were lighter but more rapid, producing less damage to the tool, and less jar upon the machine. The machine required less weight to hold it down and was more steady; the tool also was less liable to stick in the bottom of the hole than when the blow was dead. Under favorable circumstances the "motor cost" will be more for cushioned blows than for dead ones; but the extra cost of the other items with the dead blow, would outweigh the saving. Since the maiden effort referred to, Prof. Wood has designedly made drills with cushioned blows; but if a customer desires the dead blow, the valve can be changed in a few minutes so as to produce it.

In rock drills there can practically be no using steam expansively, *i.e.*, by cutting off, as the work is done at the end of the stroke. The amount of work in foot-pounds has never been figured, and it would be quite a long task to carry it far enough for practical use, as no two pieces of rock drill just alike.

It is difficult to secure a reliable indicator card from a rock drill, for the stroke will vary not only with the pressure of the motor, but also with the resistance of the tool in the hole. The inertia of the working parts of the indicator operating as they are, 300 to 400 strokes per minute, and subject to the jar of the machine, render a truthful record practically impossible with our present appliances.

Average depth of drill holes: 3¼ feet.

Each drill made in an average 10 inches; to drill 108' of holes 132 drills had to be sharpened.

Cross-section of heading: 70 square feet.

One foot of progress of the heading required: 1 hour 17 min. drilling.

1 " 39 " loading rock.

2 drill-holes.

6·6 feet of drill-holes.

8 drills sharpened.

12·7 lbs. of giant powder.

The greatest success, however, the Brandt-drill obtained, was when the administration of the Arlberg tunnel, which was commenced a few months ago, and will be about 7¾ miles long, connecting Austria with Switzerland, decided to employ the Brandt drill on this tunnel, the largest R. R. tunnel, next to the Gotthard, in the world.

(See "Brandt's Hydraulisch Gesteins-Bohrmaschine," von A. Riedler, Wien, 1877; also, see "R. v. Grimburg, Bau des Sonnstein tunnels mit Bohrmaschinen, system Brandt," Wien, R. v. Waldheim, 1878.)

Literature of Rock Drills.

Following is a list of books, papers, etc., not previously named in this work, and bearing upon the subject of rock drilling, and on cognate heads:

Illustrated article by Jno. Darlington on tunnels and rock-boring machinery in the *Scientific American Supplement*, Feb. 21, 1878, page 1730.

Jordan's machine, illustrated in the *Scientific American Supplement*, Feb. 16, 1878, page 1,761. Two cuts taken from *Engineer*.

Tunnel and rock-boring machinery, by John Darlington, *Scientific American Supplement*, No. 109, Feb. 2, 1878, page 1730. From the *Mining Journal*.

Percussion rock-drills, by Robert Grimshaw. Paper read before the Franklin Institute, June 15, 1881. Journal of the Franklin Institute, July, 1881.

In *The Engineer* for July 27, 1877, page 69, is given an account of how food was conveyed to prisoners in a coal mine through 40 yards of coal by boring a hole with a strong iron tube, the leading end being cut into the form of a crown escapement wheel, the teeth being set alternately in and out to give the necessary clearance. The outer end was fitted with two stop-cocks with a pressure gauge between the two, for ascertaining the pressure of the air in the submerged stall. The cutter end of the tube was made of the best wrought iron pipe, and after the teeth were cut and set they were case hardened with prussiate of potash and sal ammoniac. This apparatus could bore coal at the rate of about 60 ft. per hour. The food was sent in by a food carriage.

Ordering and Using Rock-Drills.

In asking estimates and information on the subject of rock-drilling, there should be sent a rough sketch and a full description of the proposed work, giving the nature and purpose of the work, whether surface or underground; location, elevation (if air is to be used); the amount and the nature of the power, whether water or steam, if there be any on the ground; the distance the compressed air has to be carried; the depth the holes are to be drilled, the nature of the rock, the dimensions of the shaft, the present depth and the depth to be sunk; the number of points from which the levels are to be run, their dimensions and length, and the distance the compressor will be from the mouth of the shaft.

If it is for tunnel work, the present length and that proposed, the points from which drifts are to be run, or shafts sunk, their length, dimensions, and depth, and the distance of the compressor from the mouth of the tunnel. If air is to be taken from one point and carried to different workings, their relative distances and positions should be stated.

If the work is for the surface, its nature and proportion should be stated, as well as the depth to which the work is to be excavated and the extreme depth of the holes to be drilled.

In carrying power for drills, remember that it is best to place the boilers as near as possible to the drills, and the air-compressors as far as practicable, with the object of cooling the air as much as possible, and to cool the steam as little as possible. But in doing this convenience of fuel and water must not be sacrificed nor forgotten. Whether the steam pipes be long or short, they should be well covered.

In using a new drill, with steam, it should be well warmed with steam before attaching the hose; and after attaching the hose the drill should be run for a few hours with a dull point, until all the working parts are evenly headed and the drill rotates properly.

Most drills are only made only tight enough to be used with compressed air, and if intended to be used with steam, the makers should be apprised of that fact, in order that they may provide against leakage. Before attaching the drill, the steam or air should be blown through the hose in order to free the hose from any small stones or dirt that may have collected.

Be sure that the tripod legs stand on firm ground. A place should be made for each leg with a hand point; and the drill should be raised far enough from the rock to allow the pis-

ton full stroke with three or four inches to spare. Where the rock is slanting or uneven, the place where the hole is to be drilled should be pointed off level, to prevent the drill point from breaking off, and to insure a good start. The drill should be run slowly until two or three inches have been drilled, when full head may be turned on.

It is desirable that the stand should be such that the drill can be readily adjusted in any direction; that the same movement of the hand of the operator which feeds the drill up to its work should rotate it; and that the valve should be automatic, and without much complication.

The adjustability of the tripod may seem a very little thing, but it means a great deal. A machine properly mounted will work where two men cannot work with hammers upon the face of the cut. In a seam only two feet thick, like that at Port Henry, New York, the machine has to work nearly flat, with the legs spread apart.

As far as possible a percussion drilling machine should be light, compact, strong, portable, quickly set up and moved, simple in construction, readily repaired at the shaft-head, economical of steam or compressed air, rapid in motion, free from trouble in freezing up where compressed air is used. If possible, the drill should be withdrawn automatically when desired. The machine should strike the blow variably according to the rock being entered. It is desirable that the hole be churned out by the machine itself, and that the bit shank may be quickly attached to the piston rod. Some like self-feed, some do not. The machine must be readily taken apart and kept clean and in working order. It must drill deep at one setting up. The heads should not knock out, and the tappets, if there be any, should not break. The piston rod should be large.

There is some work, such as cutting slate, granite, and marble, where blasting cannot be used for fear of breaking the stone; and in this case 2-inch holes are drilled in a row, two inches apart, and the connection broken down by throwing out the rotation gear, and working out the stone between the holes with a drill bit having a flat point.

Performance of Rock-Drills.

In the Sutro tunnel the Burleigh drill, in headings 9 to 10 feet by 14 feet in trachyte rock, advanced 11 to 12 feet per day, in July and November 1874. The machines worked 300 blows per minute, with a pressure of 60 to 70 pounds per square inch. One of the Burleigh drills worked 2½ months in the Hoosac tunnel, drilling 5,300 feet of 1⅞ inch holes without any repairs.

In the *Scientific American Supplement*, Jan. 26, 1878, page 1713, Mr. W. Shankey's memoranda of the performance of the Burleigh drill are as follows: In the Hoosac tunnel, in hard gneissoid rock, greatly permeated with quartz, there were drilled 120 1⅞ inch holes in 38 hours and 40 minutes; being 16,948 inches in 2,320 minutes. The average depth of the holes was 11 feet 8 inches, the average number of inches drilled per minute, 7.3; the average number of inches drilled per machine per minute, 1·22. The drill points were changed 694 times, showing 24½ inches as the average number of inches drilled by each borer. The maximum shift's work was 12 holes drilled in 150 minutes, to a total depth of 1,728 inches, or 11½ inches per minute, with six drills, which is 1·91 inches per drill per minute. During this run the points were changed 51 times, giving 28½ inches per point.

At Steelton, Pa., one 3½ Ingersoll drill cuts 100 feet per day of 10 hours, including moves, using 7 bits and drilling 14 feet deep. The average cost of drilling as above, including labor, fuel, and sharpening bits, is 4½ dollars per day or 4½ cents per foot, by machine, while by hand the cost was 61 cents per foot.

[Paper read before the Institution of Mechanical Engineers, Bristol, England, by John J. Geach (*Scientific American Supplement*, Sept. 15, 1877, page 1410), upon the mechanical appliances used in the construction of the heading under the Severn for the Severn tunnel railway.]

In this work the headings were commenced with hand labor and concluded with the Mackean rock-drill. By hand the progress was one foot in 24 hours; with the Mackean two feet at first, the machine being worn out by the work from June to November, 1875.

The average rate was 6 feet per 24 hours. In Nov., 1875, with the Geach machine, the rate was increased to 8 feet per 24 hours, up to Jan., 1876. After this the rate was 20 yards in 6 days, or 10 feet per day; the average being 9 feet. The work was done 4,432 feet from the bottom of the shaft, which was 200 feet deep.

At 11.30 A. M. the drill carriage was moved forward and fixed, at 11.40 the machine commenced boring, and in 66 minutes had completed 20 holes averaging 2 feet deep. The firing was at 1 P. M.; the total time for boring and charging being 1 hour 19 minutes. Two drills were used; one on each side of the carriage.

Number of holes.	Boring commenced.	Time in changing drill.	Boring finished.	Total time in minutes.	Total. Inches.	Per min. Inches.
1	11.41	20 secs.	11.44	3	18	6.0
2	11.46	20 "	.51	5	26	5.2
3	.52	50 "	.59	7	28	4.
4	12.1	15 "	12.5	4	24	6.
5	.6	55 "	10½	4½	31	6.9
6	.15	35 "	19½	4½	24	5.3

These six and four of the remaining ten holes were all bored by two drills. Four drills put down 40 feet of hole, or each drill bored 10 feet before sharpening.

The machine consists of a cylinder with piston and rod and valve gear, mounted on the slide bed. The cylinder has no loose covers or split glands. The piston and piston rod are in one piece of steel, and the rear end of the rod, 1½ inches in diameter, is cut with spiral grooves with a twist of one in 32. This fits in the long cylindrical nut, the centre of which is a ratchet wheel 3¼ inches in diameter with 28 teeth on a ball, which slips over three teeth per stroke. The front end of the piston rod is 2½ inches diameter in front, and coned to 1⅛ inches at 4 inches back. There is a key way 1¼ inches by ¼ inch cut through the cone that forces the drill out when a longer one is needed. Over the end of the piston rod in which the coned hole is bored, is shrunk a ⅜ inch steel hoop to prevent the coned end of the drill from bursting the end of the piston rod, and to give some elastic slip.

The valve gear consists of two pistons on one rod slide in a cylinder; the air being taken between this piston and let in and out of the two ends of the drill cylinder. The ports are one inch long, ⅜ inch wide, ½ inch deep, and are ½ inch short of the cylinder ends, to form a cushion. The valve pistons are packed with C rings with spiral springs behind. The valve is driven by a ball tap on the piston rod through a quadrant mounted on the pin. The feed is by a 1½ inch feed screw turned by hand.

In this work the air was at first pumped into the receiver by a pair of inverted single-acting cylinders 12 x 15 inches, a trunk with a valve on the upper end, or on each cylinder driven by connecting rods from the opposite cranks on one shaft, on which the pulley five feet diameter and the fly wheel were fixed. The pulley was counterbalanced, but the 8 inch double belt would not stand the work, so a vertical engine 9½ inches by 18 inches was kept at right angles to the cranks of the air pump. The delivery and inlet valves gave trouble by breaking. Another air pump, used later on, had air and steam cylinders 13 x 18 inches, mounted vertically on two standards and coupled to the crank shaft at right angles to each other. These are so made that if the valves at either end of the cylinder work wrong, the cover can be taken off and the cylinder worked single-acting.

The air is forced in by a fan. The receiver is a 28 x 25 feet cylinder, kept nearly half full of water to cool the air. The air cylinder is jacketed to cool it, and there is also jet injection. At each end of the cylinder there is a ball clack screwed into the casting, and connected to the lower part of the air receiver by a ⅜ inch bore copper pipe. When the pressure in the air receiver is greater than that in the cylinder, a jet of water is injected into the latter.

The following data relating to submarine work at Hell-Gate have kindly been furnished by Captain James Mercur.

"For the first two years of the work, we were limited in funds and in all facilities for carrying on the work, being obliged to make standing room for our plant before we could set it up, using for the preliminary excavations temporary appliances since discarded.

"Our plant now in use you saw; the compressors are of an old pattern which we would not have bought for this work. They are those which we used at Hallet's Point.

"The compression cylinders work very well, giving good cards, and the steam cylinders are good of their class, but they expand their steam but very little, cutting off at about ⅞ stroke; otherwise I am satisfied with our machinery, and consider it suitable for work of this kind.

"This of course only bears upon the subject of consumption and repairs.

"The figures which I give you are taken from the official report for March, 1881, this being the only month in which we have had the full number of eleven drills at work continuously. (April report is not yet complete).*

"I also give you the total progress to April 1, 1881. We own our tug and stone scow, and include the pay of crews and ordinary repairs in the price of dumping. We include in the total cost of each item, coal, iron, lumber, nails, bricks, mortar, and pay of carpenters, machinists, masons, etc., so that the cost per yard each month can be checked by dividing the total expenditures for the month, as shown by General Newton's payments, by the number of yards reported by the surveyor.

"We used No. 2 extra dynamite, common safety fuse, and Atlantic Giant Powder Co. caps, for blasting.

"Wages as follows: Drillers, \$2.32; helpers, \$2.08; laborers, \$1.76; drivers, \$1.76; outside laborers, \$1.50; machinists, smiths, carpenters, firemen, etc., current New York City prices.

"All materials and supplies cost us about current wholesale rates in New York City."

Replying to a second letter of inquiry, the same gentleman obligingly gives the following figures in additional explanation of his first data.

"The cubic yards removed are measured in place, the amount being determined by the surveyor monthly, roughly checked by number of mine cars hoisted, to see that no faces are omitted.

"The average volume occupied in the cars by one cubic yard is, when broken, 1.7655 cubic yards. Inner measurement of mine car, $4.83 \times 3'.5 \times 1'.6 = 27$ cubic feet. They are loaded very uniformly and just about flush with the top. 22,441 cars contained 12,710.86 yards solid, differing but slightly from 5 to 9 (1 to 1.8).

"A cubic yard weighs two gross tons, or 4,480 lbs. nearly; the specific gravity and weight per cubic foot of 5 specimens being as follows:

S. G.	2·902	2·597	2·609	2·586	2·884.
Wt. per ft.	181·0	162·0	162·8	161·4	179·9.

Mean S. G. 2·716. Wt. 169·42 lbs. per cubic foot.

* This has been added since.

"I think the stone of less specific gravity is probably enough in excess to reduce the average weight to about the figures given.

"The quotient of lineal feet of galleries into cubic yards removed will give present average area of galleries, and average for some time past and probable to come; at the early stage of the work the galleries were carried much higher, the enlargement going on with the advance of the galleries; this enlargement was stopped about October, 1878, since which date the galleries have been driven of nearly uniform size, *i.e.*, about 10 feet wide by 7 feet high. (March gives an area of 67·5 square feet.)

"The figures for March, 1881, are typical for regular work; those for April are almost identical with them, showing as far as can be told before the report is computed, a little cost per yard.

"The extra No. 2 dynamite bought from the Atlantic Giant Powder Company, purports to contain 50 per cent. of nitro-glycerine, and is sold to the government at 45 cents per pound.

"The cost of explosive given, included also the cost of a fuse and cap. Average length of fuse per hole blasted is 3′·9. The caps hardly ever miss fire, hence average caps 1."

This information is given by permission of Colonel John Newton, Corps of Engineers, in charge of the work, which was carried on by James Mercur, Captain of Engineers, as superintendent under his orders. Mr. B. F. Boyle, overseer, a very capable and intelligent rock man, of large experience in coal and other mines, occupied a similar position upon the Nesquehoning Tunnel.*

As regards the size of drills to use: 5-inch is used for submarine work, mounted upon a scow or frame; for deep, heavy tunneling, mounted upon a carriage; and for deep rock-cutting, mounted upon a tripod. This size will drill from 1 to 40 feet deep and from 2 to 6 inches in diameter.

The 4-inch is for tunneling, heavy straight grading and quarry work, and where 12 to 20 feet holes, 2 to 4 inches in diameter, are to be made in very hard rock.

The 3½-inch and the 3 inch are the most used; being found in quarries, railroad tunnels, grading, sewers and mining; the 3½-inch drilling a 12 feet hole, 1½ to 2½ inches in diameter, and the 3-inch drilling an 8-feet hole, 1 to 2 inches in diameter. Below this size there are the 2¾ and 2½-inch drills.

For horizontal drilling the capacities are about ¼ less. As regards the capacity of these drills, we annex some figures showing what they will do in various kinds of rock, and in some cases showing the rate of hand work in the same rock.

Place or Works.	Diameter of Piston.	Size of Hole.	Material Passed Through.	Feet Drilled per Hour, Day or Month.	Cost per foot (Drill Hole.)		Saving over Hand Drilling.
		In.			Power.	Hand.	p. c.
Yellow Jacket Silver Mining Co	......	....	Conglom., Feldspar, Porph. and Quartz.	1160 ft. mo.	$1.02½	......	50
Overman Mining Co	......	....	Hard blasting Rock and Quartz.	2000 ft. mo.	.18¾	......	33⅓
Musconetcong Tunnel	5 in.	....	....	25 to 40 feet per day.	....	......	......
Sierra Nevada Mining Co.	......	....	Porphyry.	....	.32	......	50
Eagle Harbor and Ahnepee	5 in.	....	Trap and Limestone.	5387 / 4491 Working seasons '75, '76, '77.	....	......	......
Ausable Forks, N. Y.	......	1½	Feldspar, ore and Feldspathic rock.	....	....	......	50
Canada Pacific R. R., Manitoba	5 in.	....	....	207 ft. 7 in. in 3 days.	....	......	......
Millstone Point, Conn.	......	2	....	7 ft. 8 in. per hour.	....	......	......
Iron Mountain Co., Mo.	......	3¼	Iron ore, Porph. and Limestone.	45 ft. per day of 10 hours.	.23⅓	.83	66

* See tables of work at Hell Gate at end of Chap. VI., p. 390.

Place of Works.	Diameter of Piston.	Size of Hole.	Material Passed Through.	Feet Drilled per Hour, Day or Month.	Cost per foot (Drill Hole.) Power.	Hand.	Saving over Hand Drilling.
		In.			Power.	Hand.	p. c.
Knoxville, Tenn.	......	....	Marble.	140 ft. per day, 28 ft. per day hand 3 men.	....	......	......
Chicago and Colorado Mining Co.	4 in.	....	....	22 in., 1 man 10 hours. 5 ft. in 30 min. P. Drill.	....	......	......
Paxton Furnace Pa	......	2¼	Limestone	45 ft. per drill, 8 ft. hand.	.12	.50	75
Leesport	3½ in.	....	Limestone.	40 ft. per day, 3 ft. 4 in. by hand, 1 man.	....	......	......
Denver & South Park R. R.	3½ in.	....	Granite Iron Rock.	80 ft. in 10 hours, 9 ft. with 2 hands.	....	......	......
Wakefield Marble Quarries	3 in.	2	Marble.	65 ft. per day.	....	......	......
Diamond Hill Granite Co.	3 in.	.. .	Granite.	40 " "	....	......	......
Steelton, Pa.	......	....	Limestone.	100 " "	.04½	.61	......
Georgetown, Col	......	....	....	90 " "	... ...	......	......

Official Trials of Swedish Iron Institution.

Among the different rock-boring machines which have been tried by the committee appointed by the Swedish Iron Institution for the purpose of deciding which construction is the best, we have found those constructed by Mr. Richard Schram to have decided advantages, as they are more effective than the others we have tried, and consume a smaller quantity of compressed air. In consequence of their simple construction they are easily managed by the workmen, and for the same reason require less repair.

G. Bratt, *Member of the Committee.*

Dalkarlsberg Mines, *June 9th*, 1877.

Trials with Rock-boring Machines at Dalkarlsberg Mines, in Sweden, August 31st, 1877, in the Crosscut Vikern.

Rock, Hard Variety of Syenite.	35 lbs. Pressure.			45 lbs. Pressure.			55 lbs. Pressure.		
	Time of Boring.	Feet Bored.	Linien per min.	Time of Boring.	Feet Bored.	Linien per min.	Time of Boring.	Feet Bored.	Linien per min.
	m. s.	ft. in.		m. s.	ft. in.		m. s.	ft. in.	
Schram—wet	22 50	3 29	14 5	10 15	2 90	28 30	14 40	4 85	33 06
ditto—dry	39 24	3 06	7 7	20 30	2 06	11 0	....	....	....
Rand—wet	23 15	2 80	12 4	24 0	4 02	16 75	13 30	3 64	27 0
ditto—dry	39 40	2 23	5 62	28 60	2 19	9 32	....	....	....
Ingersoll—wet	17 0	1 35	8 0	21 35	3 25	15 09	14 50	2 88	19 20
ditto—dry	....	....	....	32 35	2 24	6 90	....	....	....
Burleigh—wet	Did not work.			Worked badly.			21 20	2 45	11 48

1 *Swedish* foot, 10 inches ; 1 inch, 10 linien.

COPIED FROM A PRINTED CIRCULAR RECENTLY RECEIVED.

"Having seen that Messrs. Hathorn & Co., in their circular, published an account by a 'sub-contractor' of Milford, of a trial between the 'Eclipse' and the 'Schram' drills, the following is a bare narrative of the facts connected with this so-called trial:

"Before the Schram drill was sent to Milford, the Eclipse had been at work for several months on the spot, and it had been ascertained that a drill of small size, but working at high pressure and making rapid strokes, was the best suited for the soft red sandstone in which they had to bore. The machine we sent down was of our largest size and, as we afterward found, much too powerful for the comparatively soft rock. Our machine only required 35 to 40 lbs. pressure, but as it suited the Eclipse drill to be worked at 60 lbs., ours had to be worked at the same pressure, the consequence of which was, that the blows of our machine were much too powerful, and the drill bits, cutting too deeply in the soft rock, stuck as if they had been driven into a bed of clay. The man who worked our drill, finding that the steam pressure was too great, tried to reduce it by partially closing the steam-cock, but the result of this was that he only reduced the speed of the machine.

"The Eclipse drill had been used for some time, and was well 'worked in,' and the man who worked it had had some months' experience of the rock; our machine was quite new from the works, and the man who worked a stranger in the place.

"Our man wanted to alter the shape of the drill bits, to make them more suited to the soft rock, but was not allowed to do so.

"The diameter of the drill-bits, used for the Eclipse, was $1\frac{1}{4}$ inches, and the rock displaced in a 3 feet hole = 43.92 cubic inches.

The diameter of the drill-bits used for our machine was $1\frac{3}{4}$ inches and the rock displaced in a 3 feet hole = 86.4 cubic inches, or twice the amount.

"We emphatically declare the comparative results published by Messrs. Hathorn & Co. with regard to our drill to be thoroughly misleading, and we assert that our machine not only requires less repairs than the Eclipse, but bores faster. Whenever we can obtain a chance of having a *fair* trial against the Eclipse, we shall be glad of the opportunity; in the meantime we advise intending purchasers of rock-drills first to see the two rival drills at work, and then to judge for themselves of their relative effectiveness and economy.

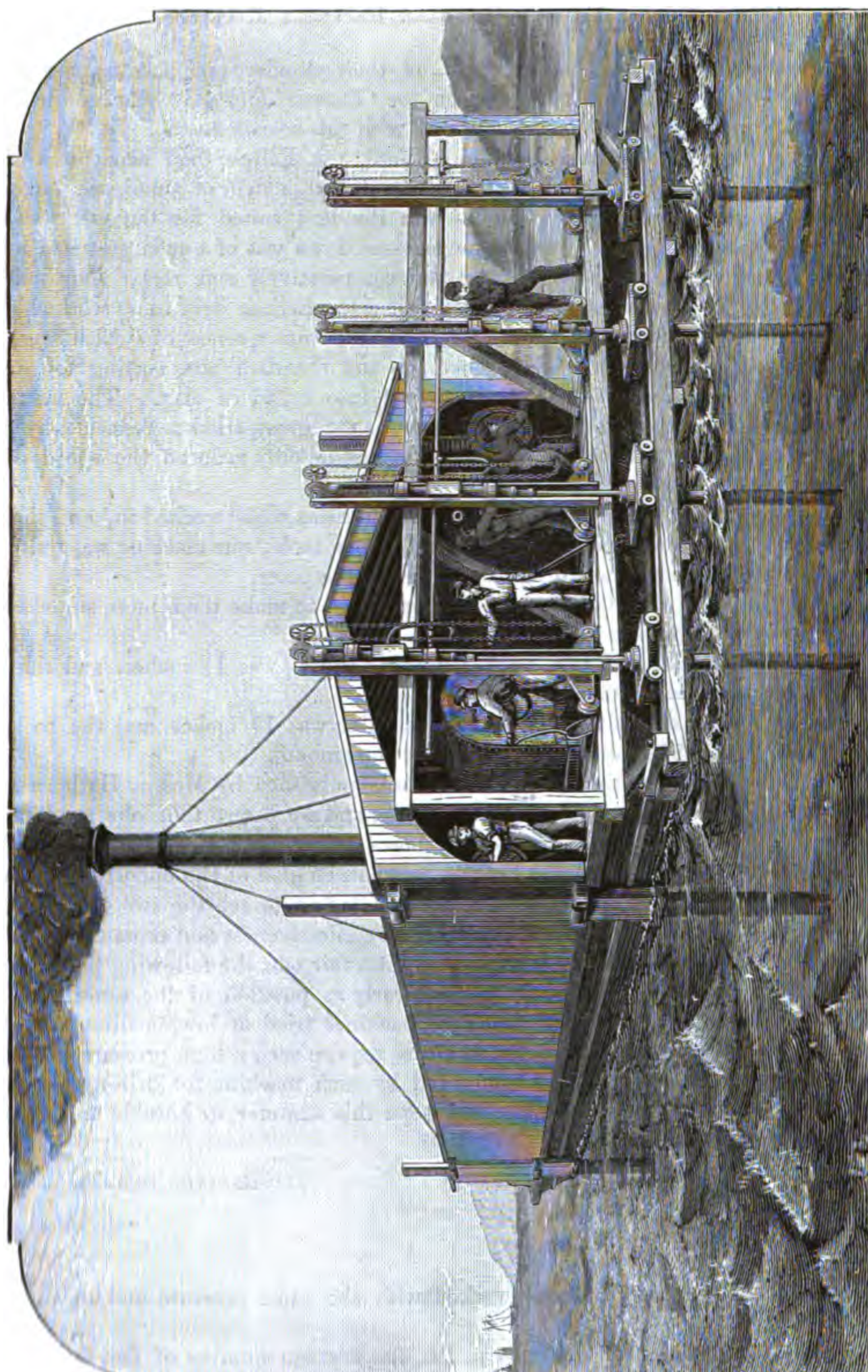
"In a trial of this description, in order to make it a fair one, the following points should be observed: 1st. The machines should be, as nearly as possible, of the same size. 2d. The drill-bits of the same diameter. 3d. The machines tried at low, medium, and high pressure, as some drills are so constructed as not to require such a high pressure as others. 4th. The consumption of compressed air required by each machine for drilling a specified number of feet should be measured, etc. We hope this summer to be able to arrange a competition on these terms.

"RICHARD SCHRAM & Co."

London, *January*, 1881.

In all these trials the the machines worked with the same pressure and in the same rock.

At the Paxton Furnace near Harrisburg, Pa., the average number of feet drilled daily with the power drill is 45 feet, by hand, 9 feet. Cost with drill 12 cents per foot, by hand, 50 cents per foot.



RAND GANG DRILL SCOW.

At Leesport, Pa., a 3¼ inch Ingersoll drill cuts 40 feet of 5 to 10 feet holes in 10 hours, where twelve men would have to be employed to drill the same distance by hand.

At the Knoxville Marble Company's quarry, the marble is hard, and is drilled 140 feet in 10 hours per Ingersoll drill with two men. By hand, three men drill 22 to 24 feet in 10 hours. Cost of drilling by steam is 1-16 that by hand; and one drill and two men will do as much work as 15 men by hand.

Diamond Hill Granite Co., Providence, R. I., one 4 inch or one 3 inch Ingersoll drill cuts 40 feet per day.

At Wakefield marble quarries, one 3 inch Ingersoll machine drills 60 to 70 feet of 2 inch holes per day.

The Chicago and Colorado Mining Co. drive their Ingersoll drills by air compressed by water power, and carried 6,000 feet in 4 inch pipe to the entrance of the tunnel, and then by smaller pipes to the drills, with 70 pounds average pressure, drill 5 feet in 30 minutes by power, where one man would drill only 20 inches in ten hours.

At Ausable Forks, N. Y., the work done by the Ingersoll drill from September, 1873 to January, 1880 was as follows: 10 hours' work per day, of which 8 were drilling; material, granite walls and feldspar ore mixed with feldspathic rock. Three drills working, and one to spare; shaft 5 to 40 feet, holes at all angles, average drilling for each drill, 10 five feet holes, from 1½ to 1⅛. Distance without sharpening bits, 2 feet; air carried 820 feet through 3½ inch pipe. Average working pressure 45 pounds. Consumption of "Arctic" drill oil, ½ pint per drill per day.

For further information as to performance of rock-drills see Chapter VI.

TABLE FROM ZAHNER, SHOWING QUANTITY OF HOT WATER TO BE INJECTED INTO WORKING CYLINDER OF ROCK-DRILLS TO PREVENT REFRIGERATION.

Absolute pressure at which the compressed air is introduced into the working cylinder.	Quantity of heat to be supplied to keep the temperature of the air from falling below zero during its expansion down to atmospheric pressure.		Weight of water to be injected into the working cylinder per unit of compressed air introduced, to keep the final temperature from falling below zero, the temperature of water introduced being—		
	Calories.	Fahr. Heat Units*.	68° F. 20° C.	122° F. 50° C.	212° F. 100° C.
2.	13.280	52.693	.134	.103	.074
3.	21.030	83.447	.212	.163	.117
4.	26.550	105.350	.262	.206	.143
5.	30.828	122.325	.311	.240	.173
6.	34.334	136.237	.346	.266	.192
7.	37.285	147.946	.376	.289	.208
8.	39.833	158.057	.402	.309	.223
9.	42.094	167.028	.425	.326	.235
10.	44.106	175.012	.445	.342	.247
11.	45.945	182.309	.464	.356	.256
12.	47.612	189.924	.480	.369	.266
13.	49.145	195.007	.496	.381	.274
14.	50.562	200.630	.510	.392	.282
15.	51.885	205.879	.524	.402	.290

* Multiply calories by 3.968, or divide by 0.252.

TABLE FOR CONVERTING CALORIES INTO ENGLISH (FAHR.) HEAT UNITS.

	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
0.	0.	3.968	7.936	11.904	15.872	19.84	23.808	27.776	31.774	35.712
10.	39.68	43.64	47.61	51.58	55.55	59.52	63.48	67.45	71.42	75.39
20.	79.36	83.33	87.29	91.26	95.23	99.20	103.16	107.13	111.10	115.07
30.	119.04	123.00	126.97	130.94	134.91	138.88	142.84	146.81	150.78	154.75
40.	158.72	162.68	166.65	170.62	174.59	178.56	182.52	186.49	190.46	194.43
50.	198.40	202.36	206.33	210.30	214.27	218.24	222.20	226.17	230.14	234.11
60.	238.08	242.04	246.01	249.98	253.95	257.92	261.88	265.85	269.82	273.79
70.	277.76	281.72	285.69	289.66	293.63	297.60	301.56	305.53	309.50	313.47
80.	317.74	321.40	325.37	329.34	333.31	337.28	341.24	345.21	349.18	353.15
90.	357.12	361.08	365.05	369.02	372.99	376.96	380.92	384.89	388.86	392.83

Multiplier 3.968, or divisor 0.252.

TABLE FOR CONVERTING ENGLISH (FAHR.) HEAT UNITS INTO CALORIES.

	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
0.	0.	.252	.504	.756	1.008	1.260	1.512	1.764	2.016	2.268
10.	2.520	2.772	3.024	3.276	3.528	3.780	4.032	4.284	4.536	4.788
20.	5.040	5.292	5.544	5.796	6.048	6.300	6.552	6.804	7.056	7.308
30.	7.560	7.812	8.064	8.316	8.568	8.820	9.072	9.324	9.576	9.828
40.	10.080	10.332	10.584	10.836	11.088	11.340	11.592	11.844	12.096	12.348
50.	12.600	12.852	13.104	13.356	13.608	13.860	14.112	14.364	14.616	14.868
60.	15.120	15.372	15.624	15.876	16.128	16.380	16.632	16.884	17.136	17.388
70.	17.640	17.892	18.144	18.396	18.648	18.900	19.152	19.404	19.656	19.908
80.	20.160	20.412	20.664	20.916	21.168	21.420	21.672	21.924	22.176	22.428
90.	22.680	22.932	23.184	23.436	23.688	23.940	24.192	24.444	24.696	24.948

Multiplier 0.252, or divisor 3.968.

PART III.

Drill Patents.

We now proceed to consider the briefs of the patents which have been granted for power-drills in this country and Europe. These lists are not intended to take the place of full description of the machines, but simply a very brief statement of some of the leading characteristics. We have, however, in foot-notes, given a more complete description of some of the prominent machines. We desire to say that we have taken great pains to make the American list very perfect. In the reports of the Patent Office, all kinds of drills were, for several years, included under the head of drills, and in the earlier history of power-drills some were classed as steam-drills, and others as pneumatic-drills. We have taken all the lists of drills, and, by examining the specifications, have excluded all but power-drills, leaving those included in the following lists. Still there may be devices used on rock-drills which are not included in these lists, but if such is the case, it is because the Patent Office has not included them under the head of drills. The list also includes tripods for mounting drills, drill-bits, drill-carriages, and other devices pertaining to power-drills.

Eighty or more patents for hand and drop drills were issued from 1849 to 1877. In the following lists a few of the later ones only, granted since 1876, are entered. Drop-drills are especially serviceable in making deep borings and for making large holes. This class of drills has been chiefly used in boring for oil and artesian wells. Hand machine-drills have not so far competed favorably for general purposes with the ordinary hand-drill driven by a hammer.

As to types of drills of this class, a good description with cuts of H. B. Bartow's drill will be found in the number of "Engineering" for October 8th, 1875. The same drill is described in the "Scientific American" for March 4th, 1876, p. 151. The American "Victor" hand-drill is another example. It is the invention of W. Weaver, of Phœnixville, Pa., and is probably the best hand-drill that has ever been tried. The bit used is peculiar in shape, and is called the "double-gouge bit," having two cutting edges with a space between.*

TABLE 21.

American Rock-Drill Patents.

Date and Number.	Name of Inventor and Brief of Patent.
Mar. 27, 1849. No. 6237.	**J. J. COUCH.**—This machine (Figs. 84, 85, and 86) was the first rock-drill ever made in which the drill was driven by steam-power and acted independently of gravity. The machine was stationary, and the drill was thrown against the rock, the tool being seized at the end of the blow by means of friction-gripes. This made an automatic feed, the drill adjusting itself at the end of each blow to the advanced cutting. It was automatically rotated during the back-stroke. It was made in 1848–'49. (See p. 195 for fuller description.)
Mar. 11, 1851. No. 7972.	**J. W. FOWLE.**—(Caveat filed May 9, 1849.) Patent reissued June 5, 1860, No. 2275. The main feature of this drill was the attachment of the tool directly to a drill-shaft or bar, which was in a prolongation of the piston-rod of an engine, so that the tool was driven by the direct action of the motor on the piston. This arrangement necessitated the feeding of the cylinder to and from the work, and rotating the tool independently of the piston. All the motions were automatic, such as operating the valve, rotating the tool on the back-stroke, and feeding the cylinder forward by means of a ratchet. Fig. 89 shows the drill for which Fowle's caveat of May 9, 1849, was taken out, and Figs. 90, 91, and 92 the drill patented March 11, 1851.†

* The "Jordan" drill in England (see "Colliery Guardian," February 1, 1878) is an outgrowth of the Weaver drill. (see p. 244).

† The Fowle drill is noted as being the type of all the successful power rock-drills made since its invention. (See p. 208 for a full description.)

TABLE 21. (*Continued.*)

DATE AND NUMBER.	NAME OF INVENTOR AND BRIEF OF PATENT.
Nov. 2, 1852. No. 9379.	**L. P. JENKS.**—Two cross-heads were connected together and the feed was automatic. Claims changing the rate of rotation and rate of feed. The pawl-holder for rotation retains its place.
Nov. 23, 1852. No. 9415.	**J. J. COUCH.**—Figs. 87 (*a*) and (*b*). The tool, passing through the hollow piston-rod, was thrown as in his first patent, No. 6237, and was seized at the end of the blow as before. This arrangement simplified his machine very much, and was the type of several drills since constructed. (See p. 158 for fuller description.)
Aug. 12, 1856. No. 15,540.	**G. H. WOOD.**—The drill was mounted on a frame, and driven forward by a spring.
May 12, 1857. No. 17,304.	**J. D. HOPE.**—Z-drill ; claims the manner of forming the wings of the drill.
July 7, 1857. No. 17,765.	**L. P. JENKS.**—The drill was forced back against a rubber spring, the recoil of which forced the tool forward.
July 7, 1857. No. 17,766.	**L. P. JENKS and G. A. GARDNER.**—The Annual Report of Patent Office has made a mistake in the brief of this patent, and we have not been able to fill the brief.
Feb. 12, 1861. No. 31,430.	**W. HARSEN.***—Reissued August 11, 1874, No. 6009. This machine had a cylinder and valve motion similar to a steam-engine. The piston was hollow ; the drill-bar, of any required length, passing through it, was moved with the piston and held by means of four wedges or cams on each end of the piston, these cams being held on the drill-bar by means of sliding collars, forced upon them by a complex arrangement, operating alternately. The drill-bar and piston were rotated together by means of a ratchet operated by a spiral groove in the shield of the machine. A tappet-bar for operating the valve was a novel characteristic of this drill. This bar had an inclined slot, in which the pin from the valve-stem worked.
May 10, 1864. No. 42,669.	**R. H. LAMBORN.**—Compressed air-drill for mining.
Oct. 18, 1864. No. 44,722.	**S. GWYNN.**—Piston struck the drill like a hammer.
Nov. 1, 1864. No. 44,862.	**S. GWYNN.**—Hollow piston-rod of the Couch type. (See No. 9415.) A spiral ratchet was attached to the piston-rod for rotating the tool.
March 7, 1865. No. 46,668.	**H. HAUPT.**—Combination of mining machinery.
Mar. 19, 1865. No. 46,815.	**C. L. NOE.**—Rotation of a drop-drill.
Mar. 21, 1865. No. 46,949.	**A. SHILAND.**—Spiral grooves on drill-bar for rotation.
April 25, 1865. No. 47,390.	**J. D. BUTLER.**—Hollow piston-rod of the Couch type. The tool was griped by means of steam pressure.
May 2, 1865. No. 47,541.	**H. HAUPT.**—Couch type. Drill was mounted between two columns.
May 23, 1865. No. 47,819.	**H. HAUPT.**—Drill had a griper-box for regulating the feed. A momentum feed is its chief characteristic.†
May 23, 1865. No. 47,870.	**J. L. SMITH.**—Tool having three or more radial cutting edges.
July 18, 1865. No. 48,785.	**W. BICKEL.**—A drill-bit which had an ordinary bit, and also at right angles to the cutting edge were two chisels or reamers, the object being to make a round hole.
Aug. 1, 1865. No. 49,129.	**J. M. MAY.**—Improvement in the drill-bit. The drill is beveled like a chisel, one wing being beveled one way and the other the opposite way, so that as it strikes it will cause the tool to rotate, the object being to dispense with all the rotating mechanism in the machine.
March 6, 1866. No. 52,960.	**W. BROOKS, S. F. GATES, and C. BURLEIGH** (Fig. 88).—This machine has a hollow piston (Couch type), the drill-bar being a screw passing through the piston, moving with it, and fed through it, by means of a nut on the end of the piston-rod. This nut is held by means of a cap or union-nut, the union-nut being screwed on to the coupling, and the coupling-nut being

* This machine was tried at the central shaft at Hoosac Tunnel in April and May, 1865, but it was not a success. The great difficulty was in the complex arrangement for forcing the collars upon the cams or wedges. It consisted of 120 pieces, and weighed 590 pounds. This was the first machine in which all the working parts were covered and protected from the dust. (See Massachusetts State Reports, Senate, No. 59, p. 33, February, 1867. Also, House, Doc. No. 4, p. 36, 1866.)

† This drill was exhibited at the Paris Exposition in 1867, and received a medal. It was patented in England (see English List, 1865, April 6, No. 981). The McKean drill has grown out of it. The feed was said to be very perfect, but neither the machine nor the principle of the feed ever came into general use. It was of the Couch type. (See p. 200 of this work.)

TABLE 21. (*Continued.*)

Date and Number.	Name of Inventor and Brief of Patent.
	screwed to the piston-rod. The feed-nut protruded through the union-nut, and was allowed to turn around in it. On the end of this feed-nut was ratched a gear, covered by a ratchet-band, with an arm upon it, all moving with the piston. The ratchet-arm moved up and down in a spiral groove, the groove being in a shield attached by screws to the cylinder. On the ratchet-band there was a pawl and two springs, one under the other. One of the springs held the pawl in gear, the other held it out of gear. As the piston moved down, the outer spring came in contact with a trip on the shield, and was lifted up, allowing the under spring to throw the pawl into the ratchet, and as the piston moved back, turned the nut round, thereby feeding the screw forward. At the extremity of its backward stroke, the pawl came in contact with another trip on the shield, which lifted it out of gear, the outer spring having a catch upon it which held the pawl when thus lifted out. The rotary motion was given by a ratchet on the coupling-nut, covered by a ratchet-band, the arm of which moved in a spiral groove in the shield similar to the other, only having a spring to hold the pawl in the ratchet; this rotated all the parts on the piston except the ratchet-bands and cross-head. The latter was held between two check-nuts on the coupling-nut. In order to operate the valve, a bar was attached to the cross-head, which communicated with a valve opening the port when the piston moved back, and shutting it when it moved forward, the air being always on the front side of the piston during both strokes. The piston having a greater area on the forward than on the backward stroke overcame the backward pressure and moved the piston ahead, and when cut off the continued pressure forced the piston back. On the back of the stationary cylinder was a reversed conical projection, which, in combination with certain other devices constituting a clamp, secured the machine to a cylindrical bar or beam in such a way as to admit of universal motion.*
March 6, 1866. No. 52,961.	**C. BURLEIGH.**—The drill was driven by two or more cylinders, the drill being attached to a cross-head connecting the piston-rods of the cylinders.
March 20, 1866. No. 53,305.	**W. R. KING.**—Reissued October 26th, 1875, No. 6716. Telescopic legs for tripod. Guide-plates for drill.
June 5, 1866. No. 55,277.	**S. F. GATES.**—Drill-bit. Four cutting edges radiate from the centre, but divide the spaces unequally.
June 5, 1866. No. 55,307.	**L. P. JENKS and G. A. GARDNER.**—Drill mounted on a column and raised and lowered by means of a screw. The entire column may constitute the screw. Machine mounted on a disc on the clamp.
Sept. 8, 1866. No. 58,175.	**R. NUTTY.**—Hollow piston-rod. Frame for mounting drills.
Nov. 27, 1866. No. 59,960.	**C. BURLEIGH.**—This was a direct-action machine, in which the drill-bar and piston are formed from one solid piece of steel. The cylinder and piston are placed within a slide, and are fed forward as the drill penetrates the rock. The movement of the valve and the operation of feeding are produced by the action of an annular projection upon the rear end of the piston-bar, and the rotation by spiral grooves in the same, in connection with a stationary ratchet and pawl. The slide is attached to the tripod, bar, or carriage by a clamp, which admits of universal motion. The rotation, feeding forward, and operating the valve were performed by the direct action of the piston in its reciprocating movement, without any of the other parts being carried with it, the piston itself being entirely disengaged at the moment of concussion, and alone receiving the strain thereby produced.†

* Although this machine was on the Couch type so far as the stationary cylinder and hollow piston-rod are concerned, yet in its mode of delivering the blow it was like the Fowle type; for the drill *was attached directly* to a piece (the screw) which reciprocated with the piston. The tool was rotated in this machine without rotating the piston, as was the case with Fowle's drill.

No part of the machine was found strong enough to withstand the strain upon it for any considerable portion of time. The union-nut proved to be the weakest point, and the breaking of this generally destroyed the part of the piston to which it was attached. Another point of weakness was the feed ratchet-band, the springs of which were almost continually breaking.

The machine consisted of eighty pieces, twenty-three of which were screws, fifteen pins, and seven pieces of cast-iron. It weighed 240 pounds, ran about 200 strokes per minute, and cost about $400. Its longest run without breaking was about five days. The run of one of them two days without breaking during the time was considered fortunate. For a table showing the list of breakages, see p. 202.

The piston-head of this machine had a diameter of $4\frac{5}{8}$ inches. The diameter of the piston-rod was 4 inches at the large end and $2\frac{1}{4}$ at the small end. (See Massachusetts State Legislative Reports, House, No. 59, February, 1867, p. 33.)

† This machine (Fig. 94(*a*)) was the first either in America or Europe that came into general use, being used not only for years in Hoosac Tunnel, but also since then in quarries, mines, and open cuts (see p. 207). The piston being free and unimpeded by any of the other parts, utilizes the full force of the motor in producing the blow. The reciprocating parts of previous machines had been the weak point, but in this machine they are not liable to break (see p. 207). Subsequent improvements were made upon the machine, which have been the subject of several patents.

Fig. 94(*a*) is a section of the Burleigh drill as used in Hoosac Tunnel in 1867. A A is the piston-rod, having a solid piston B. At its rear end is an annular cam C, screwed on the rear end of the piston-rod, which operates the valve and feed device. This piece as it reciprocates comes in contact with the opposite ends alternately of the lever G, causing it to rock on the pin *f*, thus driving the valve-rod *l*, and hence the valve. The handle *k* is for starting the valve by hand. The rotation is operated by a stationary ratchet *m*, which has a feather projecting into a spiral groove in the piston-rod A. During the back stroke the ratchet is held from rotating by a pawl which drops into the teeth of the ratchet; but during the advance stroke the piston goes forward without rotating, thus compelling the ratchet to rotate under the pawl. In some cases, a straight groove, feather, and ratchet were employed to prevent the piston-rod from turning backward.

The Feed.—The cylinder *x x* moved in a slide M M, and held by means of the screw D. This screw was connected to the slide by an iron strap or yoke E. The screw was prevented from turning by the use of check-nuts. A nut *p* was secured to the cylinder in such a way as to rotate but not reciprocate. A ratchet is made on the outside of the nut, which is engaged by a pawl, said pawl being operated by a lever, which lever was so arranged that its forward end was struck by the annular cam C, when the piston advanced so far in the

TABLE 21. (*Continued.*)

DATE AND NUMBER.	NAME OF INVENTOR AND BRIEF OF PATENT.
Nov. 27, 1866. No. 59,963	**G. F. CASE.**—Feed device.
Dec. 18, 1866. No. 60,497.	**C. D. FOOTE.**—Automatic motions, spiral grooves. Piston strikes the drill. Frame for mounting the drill. A chuck.
July 30, 1867. No. 67,323.	**R. C. M. LOVELL.**—Tuneling-machine.
Nov. 26, 1867. No. 71,829.	**S. W. ROBINSON and De V. WOOD.**—Reissued February 18, 1873. This was a direct-action drill of the Fowle type. The rotation was performed by a stationary, long, inclined spiral click engaging a ratchet on the piston-rod or drill-bar. The chuck for holding the tool is automatic in its operation. It consists of a hollow cone in an enlargement at the forward end of the piston-rod, into which are inserted three conical gibs. When the drill strikes the rock, the forward motion of the piston-rod is suddenly stopped, and the gibs, by virtue of their momentum, chuck forward, wedging themselves in between the sides of the hollow cone and the shank of the drill, and thus automatically fastening it. The feed is automatic, and is accomplished by the pressure of the motor against the forward head of the cylinder during the back stroke of the drill, and was regulated by friction gripes in such a manner that the feed advanced exactly as fast as the cutting advanced.
Dec. 24, 1867. No. 72,465.	**F. B. DOERING.**—A complex machine. The valve, feed, and rotation are all operated by small pistons. The main piston is made to distribute the steam to the small pistons. (See English Patent, January 7, 1867, No. 43, and June 10, 1867, No. 1704).
Jan. 7, 1868. No. 73,053.	**C. SCHUMANN.**—Valve, rotation, and feed, all operated by levers, etc. Much like Saxe's drill of Germany.
March 31, 1868. No. 76,131.	**De V. WOOD and S. W. ROBINSON.**—Momentum-valve movement by which the *valve* was reversed *after* the blow was struck. This was the valve movement used in the inventors' drill at Hoosac Tunnel.*

cylinder as to make the feed desirable. When the lever was thus struck, it drove the pawl against the ratchet *p*, thus turning the nut and advancing the cylinder a corresponding amount. The lever not being struck unless the cutting-in hole was so advanced as to permit the piston to advance to a definite place in the cylinder, made this feed self-adjusting within certain limits. If the cutting advanced faster than the pawl could advance the nut on the screw, the piston would ultimately strike the forward head of the cylinder; otherwise it was self-adjusting. Both automatic and hand feeds were used. The chuck G is secured to the piston-rod by means of a shank *r r*, nicely fitting a socket, and secured by an oval key *s*. The rear head *n* is steam-packed. Back of it is a sleeve *o*, somewhat longer than the stroke of the piston, so that the spiral groove in the rod cannot extend into the cylinder and permit the steam to escape. It also serves as a long bearing for the piston-rod. (See patent No. 162,258, "Improved Burleigh Drill," for heading work; tappets in it are covered.)

* The Wood & Robinson drill was covered by several patents, among which are Nos. 71,829, reissued February 28, 1873, 76,131 and 78,858. Fig. 95 is a cut of the one used at Hoosac Tunnel, referred to by Mr. Latrobe and by the State Commissioners (see p. 208). The piston-rod A A, piston B, and chuck C are one piece of solid steel. If advisable, the ratchet D may, according to the specification, also be made solid on the rod, but in this machine it was screwed on so that the process of rotating the piston-rod would keep it screwed on. The drill was attached directly to the piston-rod at C by a chuck which is automatic in its action of seizing the tool. A hollow cone is made in the enlarged part C, having its smallest end at the open end of the chuck. Conical gibs, three in number, are fitted into this cone, leaving a central hole of the proper size for securing the shank *x* of the tool. When the tool strikes, it will suddenly stop the piston rod A A, and the gibs *a a*, by virtue of their momentum, will chuck forward, and by wedging in between the shank and solid part of the chuck, will seize the tool and hold it by friction. There are some mechanical details necessary to make this a success, such as the size and slope of the gibs, which it is not necessary to describe here. This device is self-centring, adapts itself to the wear of the parts, is strong and easily repaired.

The valve is operated by the angle at projection D, Patent No. 76,131. As the piston-rod reciprocates, this projection comes in contact alternately with the projections *c c* on the momentum-piece *b*, causing the latter to reciprocate, and the projections *d d* on the opposite side of *b* cause a lever *e e*—Fig. 95—to vibrate, and this causes the valve-rod e_1 to reciprocate, and thus drives the valve *f*. The piece *b* was called a momentum-piece because it would move on, by virtue of its momentum, so as to complete the reversal of the valve in case the piston stopped too soon. The piece *b* being free to move after D had stopped, was a great compensator for irregularities of feed and the variable stroke of the piston.

The valve *f f* was a piece of flat steel having three rectangular holes *g*, *h*, *i*, and a round hole *j* for securing the valve-stem. Above the valve is a plate *k k* having a hole through it for the admission of steam. The piece *k* is smaller than the valve, and partly balanced by the steam, and was packed around its edge with rubber. With this arrangement, no packing was needed about the valve-stem e_1. The exhaust steam passed through the holes *g* and *i* directly into the air. The pieces which composed this device were simple, and some of them could be made by an unskilled mechanic. The weakest part of the machine was the momentum-piece *b*, which in after machines was so modified as to be sufficiently durable.

Rotation.—On the circumference of the annulus D is a spiral ratchet which was engaged during the back stroke by an inclined click E, but during the forward stroke the ratchet slipped under the click, going forward without rotation.

The Feed.—The machine is held from advancing in the slide R by the friction-gripe Q, and from receding by the gripe P. The ends P′ and Q′ are secured to the cylinder in any suitable manner, and the ends P and Q bind on a rib S of the slide R. When both are griping, the machine is held firmly in place. When the annular piece D advances so far as to strike the lever *m*, it will drive Q forward, where it is held by friction, and when in this advanced position the cylinder is free to move forward in the slide R. The steam now enters the forward end of the cylinder at *n*, and by pressing against the head F forces the cylinder forward at the same time that it drives the piston back, and the cylinder takes with it the gripe P which holds it in the advanced position. The machine would feed backward in the same way whenever the operator released the gripe P. It would feed forward when drilling vertically up, but it would not feed backward when drilling vertically down. It would feed from the one hundredth of an inch to two inches at a stroke. It would operate in mid-air, and feed itself into position if the drill did not strike the rock. It would probably adapt itself to a greater variety of circumstances than any other feed ever invented, but there are so many circumstances in which a screw is needed to enable the operator to manage the machine, that the inventors afterward not only abandoned this, but all automatic feed, and used a hand-feed. All the operating devices were detached from the piston, so that none of them received the shock due to the blow upon the rock.

To prevent the piston from striking the heads, a poppet-valve *o* was placed in a passage connecting the steam-ports with the ends of the cylinder, which would close automatically when the piston passed the ports, and by compressing the air then in the cylinder, make an air-spring for stopping the piston. The forward head F was made in segments (see Patent No. 78,858). The rear head was made solid with the cylinder. The machine was mounted so as to permit universal motion. (See ante p. 208 for its early history.)

TABLE 21. (*Continued.*)

Date and Number.	Name of Inventor and Brief of Patent.
May 5, 1868. No. 77,597.	**F. B. DOERING.**—Improvement on patent No. 72,465. An auxiliary cylinder is used to distribute the steam to the small pistons. (See English Patent, June 7, 1867, No. 48.)
June 9, 1868. No. 78,853.	**De V. WOOD and S. W. ROBINSON.**—Improvement in the forward head.
July 28, 1868. No. 80,386.	**C. BURLEIGH.**—Chuck for holding the drill, in which a tapered bolt passes through the chuck at right angles to the shank of the drill, and is drawn against the shank by means of a nut.
July 28, 1868. No. 80,406.	**W. HALL, JR.**—Chuck in which the forward end is split or divided, and the two parts are forced against the shank by means of two bolts.
Dec. 1, 1868. No. 84,543.	**R. GIDLY.**—Peculiar frame for adjusting in all directions.
Dec. 1, 1868. No. 84,576.	**G. PHILLIPS.**—Reissued July 12, 1876, No. 7226. For drilling large holes vertically down. The cylinder is encased in another cylinder through which it slides. In the reissue, it is claimed that the heads are bolted to each other and not bolted to the cylinder.*
June 29, 1869. No. 91,912.	**JOHN CODY.**—Submarine drilling apparatus.
Jan. 5, 1869. No. 85,597.	**S. LEWIS.**—Subaqueous rock-drilling machine.
Feb. 16, 1869. No. 86,988.	**R. C. M. LOVELL.**—Pendent rotating device in front of the cylinder.
Feb. 16, 1869. No. 87,061.	**R. NUTTY.**—Inner and outer steam-cylinders, peculiar rotating device at the forward end.
Aug. 24, 1869. No. 94,097.	**J. P. FRIZELL.**—Automatic feed device, etc.
Jan. 10, 1870. No. 98,901.	**De V. WOOD.**—Air is driven against the piston of the drill-cylinder on the opposite sides alternately by means of another piston working in another cylinder.†
March 1, 1870. No. 100,252.	**A. BLATCHLY.**—This patent has eleven claims for devices.
June 7, 1870. No. 103,899.	**S. LEWIS.**—Submarine drilling-apparatus.
Aug. 9, 1870. No. 106,197.	**H. OSTERKAMP.**—A piston-valve. Rotation performed by a pawl operated by the piston-valve. English Patent, May 20, 1870, No. 1466.
Dec. 20, 1870. No. 110,280.	**C. PECK.**—Feed-attachment.
Feb. 28, 1871. No. 112,254.	**S. INGERSOLL.**—Reissued February 16, 1875, No. 6292. Tripod consists of two ordinary legs and one forked one, the legs of the tripod having a telescopic adjustment. An automatic feeding device. (See No. 115,478.)
March 21, 1871. No. 112,885.	**A. BALL.**—Several devices.
April 18, 1871. No. 113,850.	**C. BURLEIGH.**—A pawl, to regulate the feed.
April 25, 1871. No. 114,193.	**C. S. PATTISON.**—Re-enforcing rods for fastening the forward head.
May 30, 1871. No. 115,478.	**SIMON INGERSOLL.** (Fig. 106.)—Reissued February 16, 1875. No. 6193. Internal Tappets, improvement on Ingersoll's patent of February 28, 1871. (See foot-note, p. 264).
Aug. 1, 1871. No. 117,678.	**G. PHILLIPS.**—Spring fork, for preventing a rebound of the valve in the Burleigh drill of Patent No. 59,960.

* The last device appears to be the same as one used by Fowle, see p. 206.

† This was a device for avoiding direct action. A drill was made on this plan and operated in the Michigan and Illinois Canal, in 1869–'70. It performed its functions properly, but it was too complicated and cost too much for power to drive it, and was abandoned after being used for a few weeks. A similar patent was taken out in England by one Manson. (See English List, 1874, No. 1603.)

Now that we have referred to the avoiding of Fowle's direct-action drill, we may refer to American Patents Nos. 17,765, 17,766, and 44,722; and more particularly to a drill involving the principle of the Hotchkiss air-cushioned hammer. Some forty machines of this latter kind were made by the Rand Powder Company, and several were used in the construction of the Midland R. R., about 1871. In this machine, the feed and rotation were connected by pinion-wheels, so that when the piston-rod was rotated, it would cause an advance feed when necessary. It is a curious fact that the first patent for a power-drill granted in England was on this plan. (See English Patent List.)

TABLE 21. (*Continued.*)

Date and Number.	Name of Inventor and Brief of Patent.
Oct. 24, 1871. No. 120,279.	**S. INGERSOLL.**—Spiral bar for rotating, which is cut with radial grooves in combination with the nut B.*
Nov. 28, 1871. No. 121,315.	**M. BALL and J. A. STANSBURY.**—A drill standard having adjustable legs, and several minor devices.
Aug. 6, 1872. No. 130,246.	**P. SAVAGE.**—Chuck. A spline is forced against the drill-shank, by means of one or more bolts.
Aug. 13, 1872. No. 130,412.	**J. CODY.**—Frame for mounting drill, and devices for rotating drill and hand-feed.
May 13, 1873. No. 138,777.	**De V. WOOD.**—Valve-gear involves a supplementary valve, and all is operated without shock. Steam-cushion at rear end. Feed so regulated that the operator cannot advance faster than the cutting advances. Rotation and chuck the same as in No. 71,329.†
July 8, 1873. No. 140,596.	**H. C. SERGEANT.**—Drill-carriage. A single upright column, which may move horizontally on a bed-plate. Clamp and elastic cushion.
July 8, 1873. No. 140,637.	**G. E. NUTTING and J. C. GITHENS.**—Piston-valve. Pawls of rotating device held by friction, so that they may slip if necessary. Improved chuck.
July 15, 1873. No. 140,767.	**J. DOTY.**—Improved feeding device for the Burleigh rock-drill.
July 10, 1873. No. 143,261.	**H. C. SERGEANT.**—Improvement in valve movement. Tappets in the steam-ports.
Sept. 30, 1873. No. 143,355.	**D. KENNEDY.**—Piston within the main piston, for operating the valve and feeding device.

* The Ingersoll drill has proved to be one of the best ever invented. It is covered by several patents. (See patents above, Nos. 112,254, 115,478, 120,279, 140,596, 143,261, 147,402, 147,403, etc.) The following is a description of the machine as shown in Fig. 106, which is a longi-

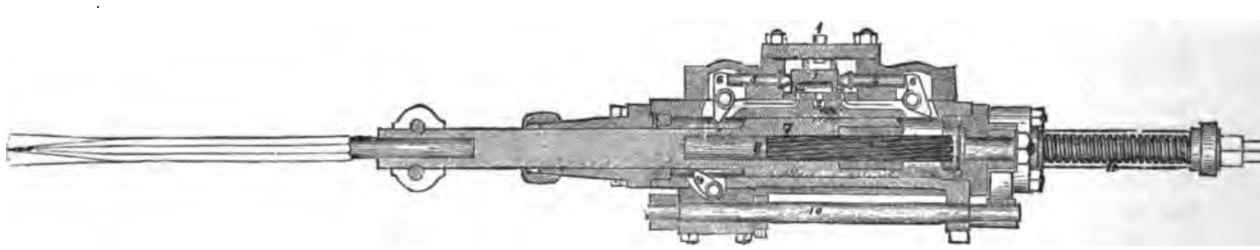


FIG. 106.

INGERSOLL ROCK-DRILL.

tudinal section: 1 being the feed; 2, exhaust; 3, valve; 4, ports; 5, valve-stems; 6, tappet; 7, piston; 8, an eight thread-screw fitting into the piston, which thereby receives the rotary motion necessary; 9, tappet, from which the motion is communicated by the bar, 10, to a pawl and ratchet movement acting on the feed-screw 11. It will be observed, the tappets and valve-stems are entirely concealed by being placed inside, thus being protected from accident by careless workmen in starting the drill, as with this they are confined in starting to simply moving a small lever, or sometimes a ring connected with the tappet-arm. When this drill was first introduced to the public, in 1872, it was the most compact of those then in the market, and soon became a favorite with many who used this class of machinery, and it has maintained a high standing in popular favor to the present time. The five-inch drill was used exclusively in the construction of the Musconetcong Tunnel, and gave entire satisfaction. Since then its use has been varied and wide-spread, being used under every variety of circumstances and in nearly all civilized countries.

† The Wood drill is an improvement on the Wood & Robinson patent of No. 71,329. The first drill after patent No. 138,777 was made in the spring of 1872. It is shown as at present constructed, in section, in Fig. 96(*a*). In machines in which the valve is moved by tappets, the tappet is struck by a projection on the piston-rod, which produces a violent shock upon all the parts connected with the valve. In this drill *there are no tappets and no shock*. The movement is as easy as the eccentric on the ordinary steam-engine. A plug-like piece *h* passes through the cylinder, and is pressed upon the piston *e* by the steam in the small steam-chest *d*. On the piston *e* is a slope, so that, as the piston *e* moves forward, the plug *h* will be forced into the cylinder a small amount, in practice less than three-sixteenths of an inch, and when the piston goes back, it will force the plug out the same amount. The plug *h* is in contact with the piston all the time, and as there is no sudden change, there will be no shock on it. This up-and-down movement reverses a small valve just under *d*. By means of this valve, steam (or air) is properly admitted and exhausted, so as to drive the piston *e*, which carries a common D-valve, and thus steam is admitted to the main cylinder. The supplementary valve under *d* has no lap nor lead. The plunger *e* is started and stopped by steam, so that it suffers no shock. There is also no dead centre. The length of the stroke may be adjusted, when the drill is running at any speed, by simply turning the pin *f*, which, by means of the spiral groove just above *d*, sets the supplementary valve in a new position. In this way the stroke may be made to vary from half an inch to the full stroke. Although this device appears to be complicated, it has the advantage of requiring but little repairs, as well as the other advantages above named. The parts wear out without breaking, which is a rare thing with this class of machines. The valve movement is favorable to a hand-feed, for the valve being always ready to go, the feed may be irregular without stopping the operation of the machine.

The rotation-nut *a* is connected with a spiral bar *b*, and the whole floats in the cylinder. The nut has a bearing *j* at the rear end. The clicks which act upon the ratchet are imbedded in the head; the large end of one is seen at *i*. The machine is secured to the clamp by means of a trunnion *k*, so as to admit of a universal motion, and at the same time permit the machine to be moved bodily away from the column, by slipping the trunnion *k* partly out of the clamp.

TABLE 21. (*Continued.*)

Date and Number.	Name of Inventor and Brief of Patent.
Dec. 9, 1873. No. 145,364.	**W. ROBERTS, JR.**—Chuck. Solid head, in which are half-boxes; said boxes being forced against the shank of the tool by means of wedge-shaped bolts.
Dec. 16, 1873. No. 145,519.	**D. MINTHORN.**—Dies for forming drill-bits.
Feb. 10, 1874. No. 147,402.	**S. INGERSOLL.**—Improvement on patent No. 112,254. Feeding device.
Feb. 10, 1874. No. 147,403.	**S. INGERSOLL, G. R. CULLINGWORTH, H. C. SERGEANT, and A. H. ELLIOTT.**—Cam-shaped tappets, and rubber buffer in front end.
March 3, 1874. No. 148,273.	**E. S. WINCHESTER.**—Flutes cut on face of piston, so that a jet of steam will cause rotation.
March 24, 1874. No. 148,924.	**R. BRYDON, J. S. DAVIDSON, and T. A. WARRINGTON.**—See English patent, June 3, 1873, No. 1991. Same parties have also two English patents in 1872.
June 30, 1874. No. 152,712.	**J. B. WARING.**—Tripod. The legs are attached to the frame, at their upper ends, by ball and socket-joints. Reissued October 19, 1875. No. 6705.
Oct. 13, 1874. No. 156,003.	**J. B. WARING.**—Tripod. Rear leg in two pieces, and can be adjusted laterally.
Nov. 24, 1874. No. 157,133.	**C. S. PATTISON.**—A double nut, to take up lost motion due to the wear of the nut and screw.
Dec. 22, 1874. No. 158,069.	**E. S. WINCHESTER.**—The feed-screw is connected with the shaft, for producing rotation by means of pinion-wheels; so that, as the feed-screw is turned by the operator, the piston and tool are also turned. Rubber cushions placed between the screw and cylinder. Rotary valve with stem pendent between the ends of a double-headed piston.*
Dec. 22, 1874. No. 158,060.	**J. C. GITHENS.**—A V-shaped disc attached to the spiral rod for rotating, and a V-shaped ring on a piston, fitting into the disc, and steam passages for forcing the piston and ring together and apart.
Jan. 12, 1875. No. 158,704.	**J. HANRAHAN.**—Cross-bit, having two bits unequally beveled, so as to produce rotation.
Jan. 26, 1875. No. 159,241.	**E. S. WINCHESTER.**—A clamp so made that the drill-slide and clamps are both fastened by means of one bolt and nut.
Jan. 26, 1875. No. 159,242.	**E. S. WINCHESTER.**—Rubber cushions placed in the heads of the cylinder.
Feb. 2, 1875. No. 159,471.	**W. F. TALLMAN and J. N. MANDEVILLE.**—Tripod with ball and socket joints.
Feb. 16, 1875. No. 159,885.	**H. P. BELL.**—A drill-bit in which the edges are straight, and the cheeks are twisted so as to produce an automatic rotation.
April 6, 1875. No. 161,616.	**N. W. HORTON.**—Chuck. One side opens on a hinge for receiving the drill-shank.
April 6, 1875. No. 161,631.	**G. E. NUTTING and J. C. GITHENS.**—Valve moved by a three-armed rocking lever.
April 13, 1875. No. 161,948.	**W. W. GOODWIN.**—Drill-bit consists of an ordinary blade and two trimmers or chisels placed laterally to the former.
April 20, 1875. No. 162,302.	**G. E. NUTTING and J. C. GITHENS.**—Tripod for supporting a drill.

* The feed-screw is connected with the rotation-bar by pinion-wheels, as in the Hotchkiss-Gardner Drill. (See foot-note to No. 98,901.

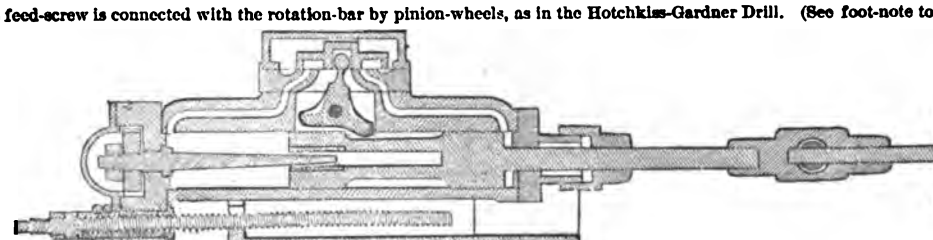


Fig. 107.

THE RAND ROCK-DRILL.

The Rand drill, of which Fig. 107 is a sectional view, is a combination of several patents. (See Nos. 162,302, 164,990, 164,991,

TABLE 21. (*Continued.*)

Date and Number.	Name of Inventor and Brief of Patent.
April 20, 1875. No. 162,419.	**G. H. REYNOLDS.**—The feed-screw is centrally behind the piston, and is attached to the end of the rotating bar, which projects through the rear head and into the piston, so that whenever the screw is turned the tool will be rotated.
April 27, 1875. No. 162,528.	**C. BURLEIGH.** (Fig. 94.)—Improvement on Patent No. 59,960. The valve-tappets are placed in the steam-ports, and the rear cylinder-head closes over the piston-bar.*
May 11, 1875. No. 163,257.	**G. H. REYNOLDS and W. TEFT.**—Chuck. It has a conical surface outside of a slit chuck, and a ring is driven down on the cone to force the parts of the chuck inward upon the shank of the drill.
May 25, 1875. No. 163,785.	**D. KENNEDY.**—Valve operated by internal tappets.
June 8, 1875. No. 164,315.	**J. H. MANDEVILLE.**—Tripod improvement on Patent No. 159,471. Combination of ball and socket with rotating shaft.
June 15, 1875. No. 164,394.	**G. H. REYNOLDS.**—Frictional rotation.
June 15, 1875. No. 164,395.	**G. H. REYNOLDS.**—Tripod. Double joints on the legs.
June 15, 1875. No. 164,396.	**G. H. REYNOLDS.**—Tripod.
June 29, 1875. No. 164,990.	**J. C. GITHENS.**—Improved shield or guide.
June 29, 1875. No. 164,991.	**J. C. GITHENS.**—Chuck. Drill is held by a gib, which is pressed against the piston-rod by a U-shaped bolt.
July 13, 1875. No. 165,646.	**E. S. WINCHESTER.**—Reissued August 24, 1875, No. 6620. Improvement on his valve device.†

166,278, etc.) The lever for operating the valve is placed in a recess between a double-headed piston, and is struck at the ends as the piston reciprocates, and the arm of the lever drives the valve. The valve is made of steel, and so constructed that it moves in the same direction as the piston in opening the ports. The chuck is described in No. 164,991. The piston-rod enters the piston on a taper, and is keyed into place. The rotation-bar is nearly triangular in cross-section, and is made very strong. The ratchet-wheel for rotation is large, and the teeth are strong. A good report has been given of the working of this drill. It has recently been used at Hell-Gate, New York.

* The first machine on this plan is said to have been made in the summer of 1872, and used in the Calumet and Hecla Mine, Michigan.

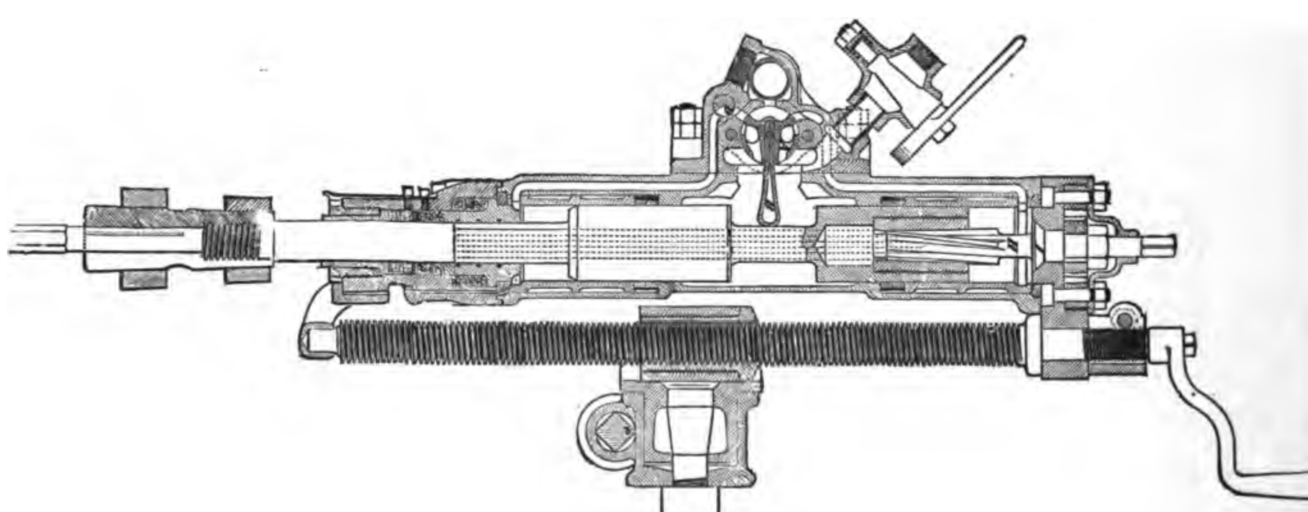


Fig. 108.

UNION ROCK-DRILL.

† The Union drill (Fig. 108) is a combination of the patents of E. S. Winchester and G. H. Reynolds. A is the valve, made of brass, which rotates on an axis perpendicular to the axis of the cylinder (Nos. 158,009 and 165,646). The pressure being on the side toward the cylin-

TABLE 21. (*Continued.*)

Date and Number.	Name of Inventor and Brief of Patent.
Aug. 3, 1875. No. 166,273.	**J. C. GITHENS.**—A buffer is placed between the rear head and a plate back of it, which plate is fastened by long bolts or rods passing to the forward end of the cylinder.
Aug. 31, 1875. No. 167,324.	**C. FERROUX.**—Foreign inventor. Advance feed is automatic, and is forced by air in another cylinder. Valve and rotation operated by oscillating engine. It is a combination of the Sommeiller and Lowe drills. (See English Patent No. 680, 1874.)
Sept. 14, 1875. No. 167,659.	**J. C. GITHENS.**—Tripod in which the cross-bar may be raised and lowered.
Oct. 19, 1875. No. 168,938.	**H. THOMAS.**—Drill-chuck in which a split chuck is drawn together by a single bolt.
Oct. 26, 1875. No. 169,121.	**G. B. SEDDON** and **W. McFAUL.**—Improvement in the rear head of the cylinder and the feed-nut combined.
Nov. 2, 1875. No. 169,389.	**J. B. WARING.**—Tripod which has no forked leg, and the parts have conical bearings, etc.
Jan. 18, 1876. No. 172,529.	**J. B. WARING.**—Drill-bit.
Mar. 14, 1876. No. 174,768.	**J. BRANDON.**—Valve device.
Mar. 7, 1876. No. 174,352.	**L. W. COE.**—Tripod in which the side-legs have two motions perpendicular to each other. Reissued April 25, 1876, No. 7079.
April 11, 1876. No. 175,931.	**L. W. COE.**—Device for operating an oscillating valve, combining the valve and rotation.
May 30, 1876. No. 178,214.	**J. B. WARING.**—Drill-chuck fastened to the rod by a ring and split at forward end. Automatic feed. Used at Perkiomen Tunnel, Pennsylvania.
July 4, 1876. No. 179,561.	**S. INGERSOLL.**—An enlargement between the ends of the piston-heads operates the valve. Bushings are put into each end of the cylinder.
July 11, 1876. No. 179,818.	**G. H. REYNOLDS.**—Feeding device.
Aug. 8, 1876. No. 180,730.	**ROE & TALLMAN.**—Chuck is screwed on to piston, and a ring which is forced forward by the momentum of the blow forces the slotted end inward, holding the drill.
Aug. 22, 1876. No. 181,386.	**E. S. WINCHESTER.**—The valve is placed in the cylinder, and operates by momentum when the tool strikes.
Aug. 29, 1876. No. 181,576.	**A. HERRING.**—Cylinder reciprocates and carries the tool. The piston-rod is hollow for admitting steam through it, and has a screw thread cut on the outside for feeding.
March 27, 1877. No. 188,734.	**THOMAS B. FORD.**—The piston-rod is provided with zigzag grooves, in which spring pawls work to give the piston a rotary movement on the down-stroke. The piston is provided with similar grooves, which serve as spring passages to make connection between a steam port in the centre of the cylinder and passages in the walls of the cylinder which lead to the ends. The exhaust takes place through similar passages on the opposite side of the cylinder.
March 6, 1877. No. 188,045.	**JOS. C. GITHENS**, New York City.—Instead of having large steam chest on outside of cylinder, which would prevent the drill being used close to the top of the cutting, there is a sleeve provided with curved slots, a lengthwise cavity, and straight lengthwise slots, in combination with the cylinder, piston, and steam inlet-tappets, to adapt it to serve as a valve. The middle piston is made smaller. and surrounded with a sleeve; the space between the middle part of the sleeve serving as a steam chest. The steam is let in through guide-pins screwed into the opposite side of the cylinder, their inner ends projecting so as to enter curved slots in the sides of the sleeve, by which the sleeve is turned.
March 13, 1877. No. 188,316.	**C. SWAN**, Trenton, N, J., Assignor to the **J. A. ROEBLING'S SONS & CO.**—Machinery for drilling oil and artesian wells. A drum, wire rope, automatic feed device as substituted for the walking-beam, hemp rope, and short male and female hand-screw. Drum turns on its shaft, and is given either a vibratory or a rotary motion at will. The rope is turned around by hand. There is but one loop between the drum and the drill, except that over the derrick-pulley.

der, and the ports on the opposite side, the valve will always be kept tight on its seat. Motion is imparted to it by means of a double lever or tappet (B), which enters into a recess turned into the central part of the piston. This lever is made of spring steel, and sufficiently light to allow for a considerable amount of yielding when the piston strikes it, the two leaves coming into successive action. Thus the destructive shock resulting from the violent contact with the piston is reduced to a gradual cushioning, which is claimed to greatly enhance the durability of both the valve and tappet. The regulation of the flow of steam is the same as in other rolling valves for steam-engines, and requires no special explanation. The valve is held from sliding sideways by bonnets, that at the same time receive the central journals cast on the valve. One of these journals passes through the cover and carries at its end a small hand-wheel, which serves to move the valve from the outside, when the movement of the piston leaves it in its central position, covering both steam ports, and causing a stopping of the drill. The rotation of the drill is effected by a twisted iron bar II, the details of which, also the manner of feeding, etc., are manifest from the cut.

TABLE 21. (*Continued.*)

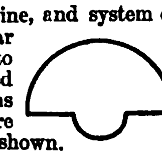
Date and Number.	Name of Inventor and Brief of Patent.
March 27, 1877. No. 188,734.	**THOS. B. FORD**, Newburgh, N. Y.—Rock drilling machine. Piston is provided with a series of spiral passages, and while receiving rotary motion receives steam for the whole stroke. Piston-rod has spiral and straight grooves, and pawls, by which it rotates the piston. Feed-screw and nut project in the hollow piston. Part of the nut projects through the cylinder head, and is cut by two or more slots, and turned tapering at the upper end, over which a nut is fitted to press the parts of the split nut together, and get friction upon the feed-screw.
April 24, 1877. No. 189853.	**THOS. B. FORD**, Newburgh, N. Y.—Tripod for rock-drills. There is a vertical bar upon which the drill may be attached, and move in any direction. Upon this there are lengthwise undercut grooves, converging toward their upper ends, in which adjustable arms are held by concave washers and screws. Steady weights are readily movable on the arms. The points upon which the tripod stands are bars, pointed at their lower ends, flattened and tapered toward their upper ends, and adjustable in and through slots in the weights.
May 1, 1877. No. 190,332.	**A. J. MERSHON**, Warsaw, Ind.—Rock-drilling machine. Cam disc has an arc-shaped slot in the end of which is journaled a concave roller, with an arm placed loosely on upon the drill-rod and extending through the slot of the disc, so as to be engaged by the concave roller as the disc is revolved.
May 1, 1877. No. 190,232.	**M. JOHN**, Pittston, Pa.—Drill-bit. Consists of a flat blate of uniform width, and having flanges at both edges and on both sides. The end of the blade extends beyond the terminations of the flanges, and the lower edge is curved inward, and the lower and side edges are sharpened. Each flange-edge is bent outward at the lower end to form a curved lip, which is rounded and sharpened at the edge. The projecting portion of the blade cuts the coal with its end and side edges, and the edges of the lips ream the opening.
May 15, 1877. No. 190,699.	**R. ALLISON**, Port Carbon, Pa.—Rock-drilling engine. Two connected pistons with hollow connecting stem. In and around this stem is a recess with inclined ends, alternately operating two blocks with inclined ends, which pass into the steam-chest and abut against projections upon the valve, which is oscillating and is operated by the blocks. The feed-screw is operated by the same inclines upon the piston-stem, a suitable opening being cut through the cylinder-bottom, with a spring sliding-block fitted therein. If the rock be very hard, the piston may make several strokes without feeding.
May 15, 1877. No. 190,871.	**O. B. KEELEY** and **J. FLEMING**, Spring City, Pa., Assignors to themselves and **E. S. SHANTZ**, Philadelphia.—Rock-drilling machine. Improvement upon No. 142,824, Sept. 16, 1873. Combination of the upper portion of a standard, and the drill-carrying portion pivoted to this, to allow of the drill being adjusted vertically, and the lower portion of the standard pivoted to the upper portion, so that the drill may be adjusted laterally. There is a central screw to the upper portion, to thrust against the tunnel roof.
May 16, 1877. No. 193,328.	**G. F. GLASS**, Allegheny, Pa.—Rock-drilling hole-cleaners. There is a cylindric metallic can with a disc-valve across its entire area near the bottom, and operated by the handle of the can.
May 29, 1877. No. 191,307.	**W. R. BURT**, East Saginaw, Mich.—Expanding rock-drill. Hinged wedge-shaped expanding arms with interior guide-grooves, and a vertically-sliding wedge-piece guided therein, and an operating screw-shaft turning in the head of the arms and in the wedge-piece. When closed, the arms form a cylindrical tool.
June 19, 1877. No. 192,068.	**A. A. GOUBERT**, New York City, and **N. W. PRATT**, Brooklyn, N. Y.—Rock-drill. Truncate piston with tappets reciprocating therein. Live steam is let in to the upper and smaller end of the piston during the whole working-stroke, and at the end of the working-stroke communication is opened between the opposite ends of the cylinder, admitting the steam which has caused the working-stroke to the lower and larger area of the piston. Reciprocating valve, with stem having four collars; reciprocating tappet, double-acting spring-stop. Two of the collars receive and give to the valve-stem the motion of the tappet, and the other two the thrust of the spring-stop, so that if valve overruns it will follow back the tappet on the reverse stroke, and return to one of its two normal positions, with the ports wide open. Outer end of the piston secured to a cross head, the projecting portion of which forms a nut engaging the male thread upon the upper portion of the tool-stock. Lower end of the nut is fastened to a tube affording a bearing for the carrier-bar, and reciprocates with the nut. From the end projects a tappet perforated to receive the valve-stem. On the side opposite to the tappet an arm projects from the cross head, and is perforated to receive the rock-shaft. This arm is formed into two spiral wedges upon opposite sides of the rock-shaft, and inclined in opposite directions. These wedges reciprocate with the drill-bar, and work upon a shell cam fastened to the rock-shaft. From the rock-shaft the feed is given, proportionately to the depth of the last blow. There are two feed-tappets, one giving quick movement during the latter part of every working-stroke, and the other a slower motion in the opposite direction, to feed the stock more or less, according to the depth of the last cut.
July 3, 1877. No. 192,788.	**H. N. PENRICE**, Hatfield, England.—Rock-boring and tunneling machine, and system of tunneling. A ram armed with reciprocating chisels is used to cut an annular groove, and the core removed. The ram-cylinder has a diameter nearly equal to that of the annular groove; and the upper part and sides of the bore are enlarged in advance of the cylinder, by holes formed by three or more non-turning arms fixed to the ram behind the cutting head. The cutting-pieces on these arms are preferably of the shape of a cross with a ring around it. Final shape of bore as shown. 

TABLE 21. (*Continued.*)

Date and Number.	Name of Inventor and Brief of Patent.
Aug. 21, 1877. No. 194,419.	**W. W. DUNN**, San Francisco, Cal.—Machine for drilling rocks.—Slide-valve moves at right angles to the piston axis, and is thrown by a rock-shaft worked by a piston, and arms above the cylinder. This rock-shaft has another arm working through the exhaust port, and projecting into the cavity of the slide-valve. Those two arms are acted upon by a conical protuberance on the piston-rod. The feed-screw is at the bottom of the cylinder. and the feed-nut is attached to the frame on which the cylinder slides. Parallel with the piston-rod there is a rock-shaft having an arm actuated by the side of the piston-rod boss. By ratchets the feed is given through the spiral rod. The cylinder has the throttle-valve closed by a lever when the drill has been fed all the way out.
Aug. 24, 1877. No. 3218.	**GEO. WARSOP** and **HENRY WALKER HILL**.—Drill stand. Broad V or concave foot at the base of the stand, and two pairs of cheeks in which are held two claws.
Oct. 30, 1877. No. 196,574.	**THOS. N. GAINES**, Au Sable Forks, N. Y.—Rock-drills. The cam-shaft groove actuating the slide-valve is formed of two separate pieces of metal, so that they may be made of hardened steel without breaking in hardening.
Nov. 6, 1877. No. 196,788.	**URIAH CUMMINGS**, Buffalo, N. Y.—Hand rock-drills. There are lifting-dogs applied to a lever, with tripping device on a clutch head; with ratchet teeth on its upper end.
Nov. 13, 1877. No. 197,075.	**J. A. ALBRIGHT**, Fayetteville, Tenn.—Expansion rock-drills. There are lateral cutting-blades in combination with a spring-seated end-piece, so as to be projected laterally from the drill-stock by the impact of the end-piece, and withdrawn when the driil is drawn back, thus enlarging the hole laterally.
Nov. 30, 1877. No. 197,080.	**M. W. BARSE** and **H. W. MOORE**, Olean, N. Y.—Drill cable measure. Grooved operating-wheel, with its face graduated and provided with serratious in combination with a long shaft and suitable worm-wheel and counting-devices.
Dec. 25, 1877. No. 198,086.	**PRESCOTT B. BUCKMINSTER**, Belleville, Nev.—Chuck for rock-drilling machine. Chuck is formed of a cylinder having one portion separated by a cut extending from near the piston-rod end, curving inward and toward the drill end until the cut extending across the full diameter reaches a point tangent with the axis of the bar; then still across its full diameter to a point near the end of the chuck; then around the circumference, just half around; this cut being met by a circular cut, a parting being made by a diametrical cut. This cannot very well be described without reference to the drawing, although it is a very simple cut.
Dec. 25, 1877. No. 198,625.	**FRANKLIN KEENAN**, Brownsville, N. Y.—Portable rock-drill machine. The machine is mounted upon wheels, the drill-cord is supported by a swinging and removable mast; the drill is advanced or retracted by a bell-crank lever having an elastic bumper.
Dec. 25, 1877. No. 198,486.	**P. S. BUCKMINSTER**, Belleville, Nev.—Chuck for rock-drilling machine. The chuck is formed of two pieces screwed and keyed upon the piston-rod. It is separated by a cut extending in quadrant from the circumference to the axis, along the axis, and then at right angles to the axis.
Jan. 22, 1878. No. 199,389.	**S. WINCHESTER**, Boston, Mass.—Rock-drill, downward. Improvement upon his patent No. 181,386, Aug. 22, 1876. Cylinder case has an exterior male screw to cause feed; it rotating in the female threaded screw-case of the stand. There is a friction or spring guide-stem for the valve; and wooden blocks as buffers to the valve. The inlet-ports are in the cylinder head, and there is a hollow or grooved annular collar permitting the cylinder to be turned without interfering with the steam supply.
Feb. 5, 1878. No. 200,024.	**A. BRANDT**, Ebensee, Austria.—Hydraulic rock-boring machine.* Abutment for the machine is formed by a hydraulic cylinder and piston forced between the sides of the rock chamber. There are two hydraulic engines, one each side of the apparatus. These engines rotate the cylinder and tool, and by means of a worm and worm-wheel, the feed is hydraulic.
Feb. 20, 1878. No. 205,105.	**EDWARD E. SWEET**, Olean, N. Y.—Rig for digging oil and other wells. There is a clutch by which the bull-wheel may be driven or not, without throwing the tug-rope on or off.
Feb. 26, 1878. No. 200,690.	**CHARLES BURLEIGH**.—The outer sides of the so-called compartments of the valve-rod are done away with, and the air or steam admitted into the passage, where the valve-moving lever will act at once upon the head of the valve-rod and move it in advance of the lever after the lever starts the valve, so as to permit free steam to meet that end of the lever. Instead of the stem of the valve-rod extending outside the cylinder through a stuffing-box, in which case one end of the rod is subjected to atmospheric changes (as in patent 162,528), the valve-rod is entirely within the casing, and its surfaces at its ends, against which the steam works, are equal; and the end of the valve-rod instead of going into the air through a stuffing-box, is done away with, with the intention of reducing the weight of the valve-rod and its friction, and lessening the power it takes to operate it. Besides this, both ends of the valve-rod are always of the same diameter, and the valve-rod not liable to be broken or bent by an accidental blow.

* See foot-note on Brandt drill, with cuts, p. 245.

TABLE 21. (*Continued.*)

Date and Number.	Name of Inventor and Brief of Patent.
	Instead of the hand-rod to move the valve-rod passing through a hole in the extended valve-rod, there is a finger on a shaft or pin entering a slot in the back of the valve.
March 19, 1878. No. 201,569.	**JULIUS H. STREDDINGER**, N. Y., **JAS. R. F. KELLY**, Brooklyn, and **KELLES KARROW**, Greenpoint, N. Y.—Apparatus for subaqueous drilling, laying foundations, etc. Frame or staging with sliding legs, to support the mechanism, and an independent scow to support the frame when the struts are raised.
April 2, 1878. No. 202,060.	In **H. C. SARGENT'S** patent the tripod has two fixed legs, which are fastened to the cross-head, and one adjustable leg pivoted to the cross-head, there being an adjustable rod to regulate the spread of the loose leg. The cylinder is slid along the guide-rods, passing through the cylinder flanges. The valve is cylindrical, and slides upon a central bolt. The steam-chest has seven ports, of which three are the ordinary steam and exhaust ports of the main cylinder, and the others, ports connecting with the central encircling chamber of the piston. The valve is moved without tappets, racy arms, or any other mechanical connection with the piston.
April 16, 1878. No. 202,338.	**W. H. ELLIOT**, N. Y.—Rock-drill. See patent of May 29. 1877. To prevent injury to the piston and cylinder by a cleansing of the drill-tool, there are elliptical springs within the lower ends of the vertical shaft, and between it and the shank of the rock-drill, serving as a flexible guide-way. To prevent the drill from raising by recoil, there are within the vertical shaft and upon the end of the shank, a wedge and a weight, which follow down and rest upon the shank, and if there be tendency to recoil, wedge the shaft tight. Feed is by an auxiliary cylinder and piston.
April 16, 1878. No. 202,372.	**JOHN PRICE LEAVITT**, Assignor to **ANDREW M. PRICE** and **JAMES C. PRICE**, Carroll Co., Ohio.—Coal-drilling machine. Machine is gently pressed to its work by a lever and spring.
April 16, 1878. No. 202,415.	**THOMAS CUMMINGS**, Hackensack, N. J.—Platform for submarine rock-drill. A floating frame work, with vertical tubes having lugs or spuds passing through these tubes.
May 28, 1878. No. 204,143.	**J. B. ELLIOTE** and **GILBERT R. ELLIOTE**, New Brunswick, Can.—Well-drilling apparatus. Vertical steam-cylinder with hollow piston-rod; automatic lifting and feed-cylinder, with its piston and piston-rod working in this hollow rod. Drills attached to the smaller piston-rod may be suspended upon a column of water in the automatic feed-cylinder. This feed cylinder has passages connecting with the lower end of a pipe, the upper end of which has two passages, one controlled by a feed-valve, and the other by a valve. The feed-valve is closed by a spiral spring and by weights.
June 18, 1878. No. 202,023.	**JNO. GRUBS**, Lickingville, Pa.—Oil drill-bits. The circular drill has two side-flutes, and the cutting-edge is concave.
June 2, 1878. No. 202,060.	**H. C. SERGEANT**, New York City, N. Y.—Rock-drills.
June 18, 1878. No. 204,990.	**STEPHEN MOREY**, Syracuse, N. Y.—Hand drill.
July 9, 1878. No. 205,901.	**CHAS. D. PIERCE**, Philadelphia, Pa.—Hand rock-drills. The drill-rod is raised by a bar in the semi-circular slot in the driving-wheel, and the blow given by the compression of the spring.
July 16, 1878. No. 205,998.	**SAML. G. BRYER**, Saugus, Mass.—Rock-drill. There are two annular grooves in the cylinder, connected by a steam passage opening into one groove near the inlet-port. The piston is in three parts, separated by two annular grooves, and there is a shallow annular groove in the middle part of the piston. In this last passage there is loose a self-acting valve. Upper part of the piston-head is notched, aud the piston is rotated by a pawl.
June 27, 1878. No. 206,067.	**ROBT. ALLISON**, Port Carbon, Pa.—Feed-screws and nuts for rock-drills. Lost motion is taken up by an adjustable sleeve-nut, held in place by a screw bearing upon the adjustable nut.
July 23, 1878. No. 206,320.	**GEO. W. HAYDEN**, Worcester, Mass.—Drill-chuck. (Burleigh; machine tools.)
July 24, 1878. No. 208,448.	**EDWARD S. WINCHESTER**, South Boston, Mass.—Rock-drill. Slide valve is moved in one direction by the positive action of the piston through an extension of the stem, and is held by a detent when forced back against the pressure of the steam, and is released by the action of the piston-head. To prevent accumulation of water in the cylinder, the lower port is extended directly outward, and the upper port extended down below the mouth of the lower port, so that the water can flow freely from both ends of the cylinder.
Aug. 20, 1878. No. 207,122.	**JOHN JULIEN**, Dubuque, Iowa.—Expanding rotating rock-drill. The drill-rod is tubular; a screw-rod passes down through it and throws out a latch containing the cutters.

TABLE 21. (*Continued.*)

Date and Number.	Name of Inventor and Brief of Patent.
Aug. 20, 1878. No. 207,162.	**SAM'L. G. BRYER**, Saugus, Mass.—Rock-drill. Piston has a broad, annular groove about its central part, with its upper edge beveled; annular grooves midway between the piston ends and the broad groove; these grooves having suitable corresponding parts in the cylinder. The feed-ratchet is driven by a pawl, which is thrown by means of a pin projecting into the cylinder at right angles to its axis, and pressed out by the beveled edge of the piston groove, being returned by a spiral spring.
Sept. 10, 1878. No. 207,885.	**AARON J. MERSHON**, Warsaw, Ind,—Hand rock-drilling machine. Improvement upon No. 190,232. To the sills of the frame supporting the working parts, at a point between the disc-wheel and the drill-shaft, is an upright guide-plate, one edge of which is curved in the form of the arc of a circle, very nearly corresponding with that described by the slot in the disc-wheel. This prevents the arm from flying out of the slot. The lifting arm has an eye which bears under the portion of a second arm, causing this last to rise with the drill-shaft, compress one spring and expand another.
Nov. 26, 1878. No. 210,189.	**URIAH CUMMINGS**, Buffalo, N. Y.—Hand rock-drill. Spring is compressed by two hand-levers geared together so as to move in opposite directions, and carrying pawls which alternately lift the drill.
Dec. 17, 1878. No. 211,022.	**THOS. B. JORDAN** and **THOS. R. JORDAN**, London, England.—Rock-drill. Improvement upon No. 201,017. To let a small additional charge of air into the cylinder at each down-stroke, the lower portion of the piston-rod is enlarged to form a trunk nearly of the diameter of the piston, this trunk passing through a leather collar turned upward. A number of grooves are cut in the gland to let air in during the up-stroke. To prevent the air-pressure from overcoming the power of the man at the handles, there is an escape valve. The packing in the upper end of the cylinder is a metal ring of a semi-circular section, covered with a leather ring. There are holes in this metal ring through which the air passes and forces out the leather. The rotation is adjustable by changing cogged collars.
Feb. 25, 1879. No. 212,598.	**GEO. M. GITHENS**, Brooklyn, N. Y.—Friction rock-drill. The ends of the valves project alternately into a live steam chest, within the body of the central part of the cylinder, and in the pathway of the piston, so that the valve is moved by the piston direct. The valve slides endwise in the arc of a circle, and is actuated by inclines upon the piston.
March 25, 1879. No. 213,663.	**J. B. JOHNSON.**—Rock-drill. The working cylinder travels in a steam-tight casing, with a stuffing-box and an induction-port in the lower head, and outward-opening valve in upper head. Working cylinder is fed along in this casing without screw gear, at end of travel closing induction port and stopping; and being withdrawn with the drill by single action of the steam. Drill rotates by groove inside hollow piston-rod, in which spiral projection in the head works. Working cylinder is kept from rotating in the casing by a friction-ring. Dash pot formed by upper end of working cylinder and upper head of casing. Steam enters lower casing head, passes between casing and working cylinder, and pressing the upper head of the working cylinder, except when bushing in piston is removed from central exhaust pin. Steam from above the piston is exhausted at the front end of the hollow piston-rod, the drill rotating during the up-stroke. The exhaust pin entering the bush at the top of the rod, cuts off exhaust and causes compression, which continues until the projection on the lower part of piston-head raises valve and lets live steam above the piston. To withdraw the drill from the hole, the valve in the upper head of the casing is opened, thus destroying the balance and causing working cylinder to be raised. Working cylinder slides in an outer casing under the action of the motive pressure. Opening valve in the upper head of casing causes steam to withdraw working cylinder. Exhaust is through piston-rod, and closed by central exhaust pin. Steam port is closed by elastic ring operated by piston and projection on piston-rod.
April 22, 1879. No. 214,704.	**HENRY RICHMANN**, San Francisco, Cal.—High-speed rock-drilling apparatus. Cylinder revolves in the case to rotate the drill. Controlling valve is in the piston, and moves in the same direction as the piston. Taper screw claimed for holding the drill-rod.
May 6, 1879. No. 215,101.	**URIAH CUMMINGS**, Buffalo, N. Y.—Hand rock-drills. Between the actuating lever and the clutch head there is an auxiliary lever to which the spring power is applied, thus relieving the rotating gear from the pressure of the spring. The drill-frame is journaled in a stationary frame, so that it can be used at any inclination.
May 6, 1879. No. 215,152.	**THOMAS MURPHY**, New York City.—Sliding valves for rock-drills. The valve is shifted by the piston before it has completed its stroke, to shut off steam in rear of the piston, and admit it in front; to cushion the piston upon live steam, and make its return movement a continuation of its rebound.
May 20, 1879. No. 215,622.	**JAS. E. HUGHES**, Barnhart's Mills, Pa., Assignor to himself and **MICHAEL O'BRIEN**, same place.—Drill jar. Jar is composed of two links, rounded upon their lower sides, and coupled like the links of a cable chain, but made elongated and rounded on their exterior faces to conform

TABLE 21. (*Continued.*)

Date and Number.	Name of Inventor and Brief of Patent.
	to the small diameter and circular character of the hole in which they reciprocate. The end of the bar is made rounding in cross section to form a cylindrical chamber and give as large a striking surface as possible.
June 10, 1879. No. 216,437.	**T. E. MORPETH**, Plains, Pa.—Hand rock and coal-drilling machine. The drilling machine is swiveled in a hole in the end of the bar which is inserted into the face of the coal or rock, and wedged fast.
Aug. 4, 1879. No. 228,529.	**HARRIS MORSE**, Columbia, Cal.—Diamond boring rock-drill machine. Improvement upon Leschot, July 14, 1863, and Severance, Oct. 26, 1869. Drill is driven and fed by hydraulic pressure. Tube through which the tubular drill-shaft passes, goes through the cylinder. Drill is driven by the water upon a wheel in the cylinder-case back of the main cylinder. Drill is fed by rods extending from a yoke upon its cross-head to an annular piston in the water-casing around the drill-shaft case in the main cylinder.
Aug. 19, 1879. No. 22,888.	**JOHN GREY CRANSTON**, Newcastle upon Tyne, England.—Percussion rock-drill. The tool may be thrown in or out of rotation by means of a hand-wheel and clutch operating the rotating mechanism.
Sept. 2, 1879. No. 219,183.	**THOS. J. WILLIAMSON**, Carson City, Nev.—Drill sharpeners. Hinged iron blocks contain three pairs of steel dies of graduated size, so that the drills may be swedged gradually to shape and size.
Nov. 11, 1879. No. 221,646.	**E. J. WILLIAMS**, St. Louis, Mo., assignor of one half to **L. A. PRATT**, same place.—Rock drills. Two part expanding drill, the lower portion having cutting edge eccentric to the axis of the drill.
Dec. 23, 1879. No. 222,972.	**JOHN B. WHEAT**, Joplin, Mo., assignor of one half to **JOHN BLAKE**, Aurora, Ind.—Feed-screw for drill. Feed screw is telescopic.
Dec. 15, 1879. No. 224,412.	**JOHN FLEMING**, Spring City, Chester Co., Pa.—Metal Rock-drill bit. Cutting edge is S-shaped, each half of the edge being beveled in one direction only, and each beveled edge merging into the bottom of a channel being formed in the lower end of the bit, the channels being deep at lower end of the bit, and more shallow as they ascend, until they disappear at their upper ends in the cylindrical shank.
Jan. 13, 1880. No. 223,474.	**JOHN BROWN**, Ishpeming, Mich.—Rock-drill. Round the middle part of the piston and round its ends there are buckets for the steam or air to strike against as they enter the cylinder, and rotate the tool.
Feb. 10, 1880. No. 224,412.	**JOHN FLEMING**, Spring City, Pa., Assignor to himself, **O. B. KEELEY**, same place, and **ENOS S. SHANTZ**, Philadelphia.—Rock-drill bit. Bit has a cutting edge made of two curves meeting each other at the central point, the edge within the limit of one curve being beveled upon one side and in one direction, and emerging into the bottom of a channel, and the edge within the limits of the other portion of the curve being beveled upon one side, but in a contrary direction, and emerging into the bottom of a similar channel.
Feb. 10, 1880. No. 9,072. Reissue.	**ROBERT MACMULLEN**, Meadville, Pa.—Original, 187,878, April 1, 1878. Link having its reins springing obliquely from the shank, forming a wedge-shaped clutch. Reins are half round at a point above the shanks, but further off get sector-shaped. Reins are half size at their base, and above are of less size to let those of the companion link lie between them.
Feb. 17, 1880. No. 224,558.	**JAS. L. PRENTISS**, Canon City, Col.—Pneumatic drill-hole cleaner. Rubber exhausting bulb and metal tube, having suitable check-valves, so that the drillings enter the metal tube.
March 2, 1880. No. 225,161.	**JOHN H. PARKINSON**, Virginia City, Nev.—Vertical cylinder with a piston and head; piston passing through lower head, and having cross-head upon opposite sides on which there are bosses carrying friction rollers. Horizontal shaft has four cams, two at each side of the cross-head; raising the piston, only the upper end is compressing, the lower end being simply the vacuum dash-pot.
March 4, 1880. No. 228,418.	**GAMALIEL TAYLOR**.—Rock-drills. This patent is for rock-drills and earth augers. This is a horse-power machine, in which the drill is raised and dropped by means of a rope upon a spool having a crank, and operated by a curved bar, the drop of the drill being regulated by a forked rod around which the cord which operates the drill is wound.
March 12, 1880. No. 229,074.	**JOHN ATCHINSON**, New York City.—Diamond rock-drill. The diamonds are not mounted upon the tube, but upon an internal insertable and removable drill-head or bit-stock, which can be removed from the tube without taking the tube from the bore. Some of the bits are upon expanding arms or supports, so that they can be withdrawn from the bore of the tube for so removing the drill. The tube serves for applying the power for rotating the drill. The bits may be thrown out

TABLE 21. (*Continued.*)

Date and Number.	Name of Inventor and Brief of Patent.
	beyond the tube, so as to cut the bore larger than the diameter of the tube, or drawn in, by means of a vertical adjustable hollow cone.
March 12, 1880. No. 227,878.	**SAM'L G. BRYER,** Saugus, Mass.—Rock-drill. Improvement upon Nos. 205,998 and 207,162, in manner of moving the pawl of the ratchet of the screw nut, to move the cylinder lengthwise in its arch. Is moved by auxiliary piston hinged to the pawl, and working in a small cylinder opening into the main cylinder. Valve chamber and ports are brought to the front of the cylinder.
April 13, 1880. No. 226,589.	**WILLIAM L. NEILL,** New Orleans, La.—Piston rock-drill. No valves upon the cylinder. Cylinder has two connected chambers of unequal diameters. Drill is projected by action of steam upon the small head, and withdrawn by steam upon larger head, partly by expansion and partly by valve-like action of the piston. (Darlington's English patent, May 13, 1873, No. 1874, has no valve, but live steam is used to withdraw piston; expansive action to drive it.)
May 25, 1880. No. 227,899.	**NATHAN W. HORTON,** Wilkesbarre, Pa.—Carriage for rock-drills. Frame of rock-drill is mounted upon a long cross bar (preferably of double T-shape), and run along this last by a rack and pinion. Patent is upon the method of revolving the bar upon its axis, and holding it in any position.
June 15, 1880. No. 228,797.	**JAS. WARD,** Syracuse, N. Y.—Hand drill machine. In this there is a reciprocating cross-head in the vertical frame, pressed downward by a spring, and given reciprocating motion by cams upon the fly-wheel shaft. The drill-spindle passes through and reciprocates with this reciprocating cross-head, and is threaded with a male screw corresponding to a female screw in the cross-head. A pawl and ratchet give the drill intermittent rotation and downward feed.
June 25, 1880. No. 227,908.	**ROBERT MAGIL,** Pittsburgh, Pa.—Portable rock-drill machine. Drill is rotated by steam or compressed air, and feed is by an independent piston worked by steam or air. Bit is cooled by a stream of water fed along the drill-bar.
June 25, 1880. No. 228,056.	**GEO. M. GITHENS,** Brooklyn, N. Y.—Steam rock-drill. (Rand.) To prevent enlarging the front end of the cylinder by concussion on the inside from the piston, or on the outside from the drill clamp, by blocks holding substances such as lead, instead of elastic substances such as India rubber. This drill employs the circular sliding valve. Valve and valve driver can be placed midway of the cylinder lengthwise, or nearer to one end than to the other, so that when the drill is being worked downwardly, and the weight of the piston and drill have to be lifted, the steam may be admitted when the piston is further away from the front head than where the piston and drill have to be projected upward.
Dec. 12, 1880. No. 235,080.	**GEO. M. GITHENS,** Brooklyn, N. Y.—Drills. There are the following new features: In the stand and carriage, the long radius bar to the jack screws, so that they may bear against the column, and not be jarred loose by the action of the drill. An adjustable ring clamped upon the column as a shoulder to support the hub of the lateral projecting arm carrying the drill cylinder, so that the cylinder may be swung in a plane perpendicular to the columns. A steam stop valve in the steam chest, handy to the left hand of the operator, instead of in the flexible tube. An axially split crank nut, with a transverse clamping screw to jam the crank nut. A split sleeve on the drill chuck, long enough to embrace the piston rod some distance above the point where the male screw thread is cut upon it.

TABLE 22.

American Drill-Carriages.

Dec. 10, 1867. No. 71,999.	**T. DOANE.**—Carriage mounted on track, having cross front cylindrical beams and projecting side-arms, on which the drill is mounted. (Fig. 100.)
Dec. 24, 1867. No. 72,466.	**F. B. DOERING.**—The drill is supported on a horizontal arm, which is extensible within or from the collar, and the collar may be raised or lowered by means of a screw cut on the column. The collar has a vertical and horizontal adjustment.

TABLE 22. (*Continued.*)

Date and Number.	Name of Inventor and Brief of Patent.
June 23, 1868. No. 79,158.	**P. SWEENEY and J. BRADBURN.**—Platform for mounting and pointing drills.
July 28, 1868. No. 80,387.	**C. BURLEIGH.**— The front cross-beam may be raised or lowered, and a passage-way through the carriage and under the beam opened for removing the rock.
May 18, 1873. No. 138,959.	**G. E. TOWNE and W. W. BAILEY.**—Improvement on Patent No. 80,387. The frame is open, and cross-bar in front overhangs the frame.
June 24, 1873. No. 140,173.	**A. P. THOMAS and W. J. EVANS.**—A single upright column, on which the drill is mounted; may be moved horizontally on a bed-plate.
May 12, 1874. No. 150,886.	**C. S. PATTISON.**—An arm is supported by a column, and the former may rotate about the column, and be turned around and raised and lowered on it. The drill is mounted on the arm, and may be moved to and fro on it.

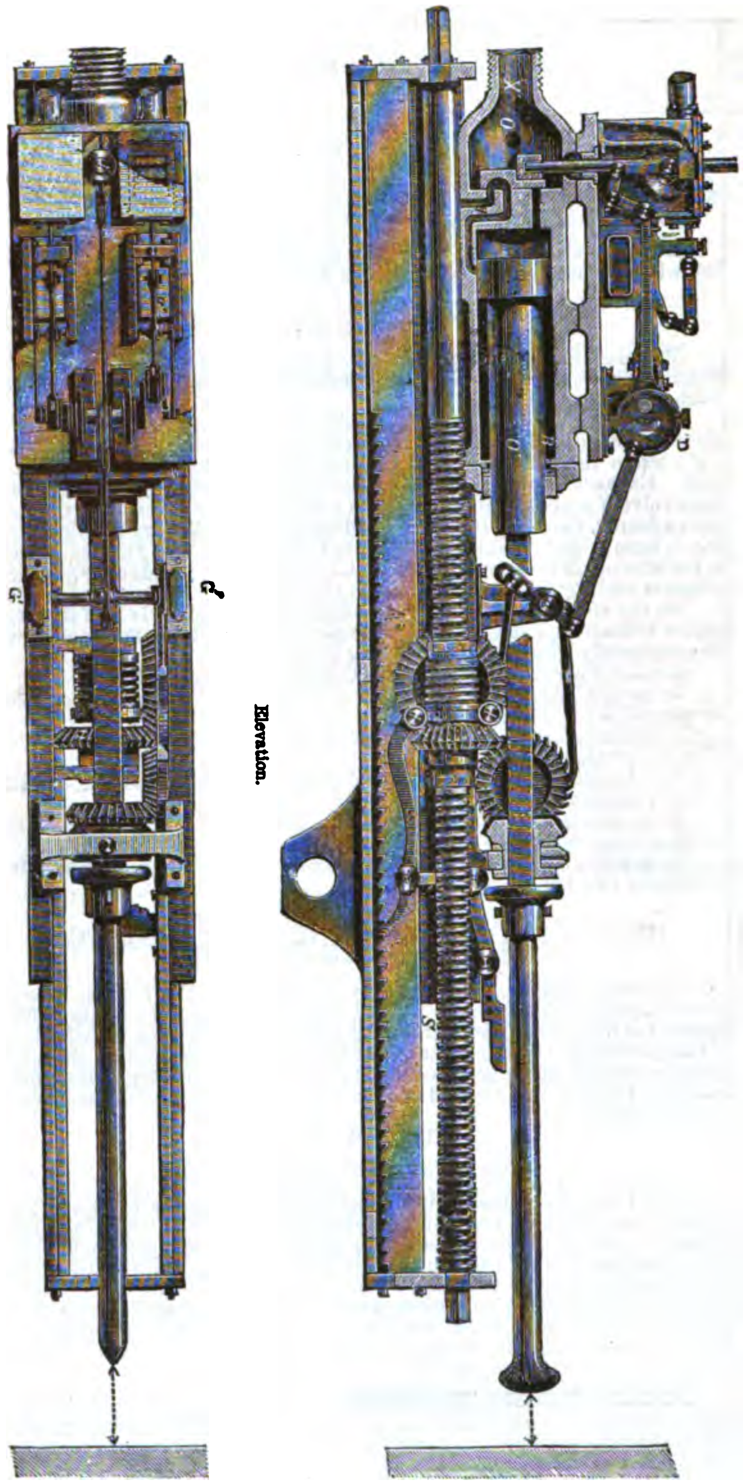
TABLE 23.

English Rock-Drill Patents.

Date and Number of Patent.	Name of Inventor and Brief of Drill.	Published Descriptions.
June 20, 1853. No. 1506.	**W. E. NEWTON.**—Only a notice for a patent.	
(First trials, 1854.) Aug. 23, 1855. No. 1918. (Also Feb. 22, 1856.) (Sardinian patent, June 30, 1855.)	**T. BARTLETT.**—An intermediate air-cylinder drives the drill, on the same principle as the Hotchkiss pneumatic forge-hammer, a well-known American hammer. The air-cylinder is reciprocated by an engine on the same frame, which engine also performs the rotation of the tool, and feeds the machine along a rack.	Full illustrations in Stapff's "Ueber Gesteinbohrmaschinen," Pl. II., 1 to 7. Description in full, p. 84. See also "Practical Mechanics' Journal," June and July, 1865; Ržiha, "Unter- und Oberbau," p. 351; Schoen, "Der Tunnelbau" (ed. 1874), p. 48.
Nov. 5, 1858. No. 2477. (Invented 1857.)	**SCHWARTZKOPFF & PHILIPPSON.**—Mounted by ball and socket. Hand-feed. Rocking-valve driven by an arm on the piston-rod. Rotation by a ball driven by valve-stem.	
Jan. 6, 1859. No. 50. (Sardinian patents, June 25, 1857, and Mch., 1861.)	**J. H. JOHNSON—(GERMAIN SOMMEILLER.)**—This is the noted Sommeiller drill, so largely used in the Mont Cenis Tunnel. The drill was attached to the piston-rod, and the valve, rotation, and feed were operated by a small engine placed in the rear of the machine. There were three types: I. (Fig. 109.) Percussion-drill. Front part of cylinder always in communication with air. Differential piston. Auxiliary cylinders for slide-valve of working cylinder, for rotary motion by ratchet and pawl, for advance by ratchet and pawl; advance automatically varying. II. (Fig. 110.) Sliding valve. Motion from one special cylinder (with fly-wheel). Rotary motion, ratchet, and pawl. Advance automatic and periodical.	Cuts of Sommeiller's drills will be found in Ržiha, "Lehrbuch der Gesammten Tunnelbaukunst," vol. i., pp. 141 and 143. Also, Ržiha, "Eisenbahn- Unter- und Oberbau," p. 357. See also "Engineering," vol. xiii., p. 391 (1872).

TABLE 23. (*Continued.*)

DATE AND NUMBER OF PATENT.	NAME OF INVENTOR AND BRIEF OF DRILL.	PUBLISHED DESCRIPTIONS.
	III. (Fig. 111.) Sliding valve by special auxiliary cylinder. Rotary motion by ratchet and pawl. Advance periodical. Stroke variable with all three. Blow cushioned in all three patents. As to the above styles, I., II., and III. of the Sommeiller drill, the following will be found to be a more detailed description :	
	I.—OLD STYLE. Patented, Sardinia, June 25, 1857. Fig. 109 shows the earliest form of the Sommeiller drill. The following description of it is from Rȥiha, "Tunnelbaukunst," etc., vol. i., p. 139 : Working cylinder B. Steam inlet, X (or inlet for compressed air). Forward part of cylinder always in communication with chamber x by opening $o\ o'$; piston therefore worked by difference of surface of forward and back part. Exhaust steam or compressed air escapes through g. For working the slide-valve, for giving rotary motion to drill, and for advancing drill as hole grows deeper, there are two special ordinary small cylinders moving an eccentric d, from which the other motions are transferred. The forward movement of the whole drill is entirely automatic—*i. e.*, if advance tends to be greater than progress made by drilling, the movement is for a while automatically suspended. On the authority of the "Traforo-delle Alpi," p. 42, it is said that the inventor himself says that this machine partly suffered from faults of construction and partly from excessively heavy blows it made. Results reported by Examination Committee (Rȥiha, p. 163): In *syenite*, 258 to 276 blows per minute; 0·029 m. drilled per minute; average of three trials. In *limestone slate*, 260 to 270 blows per minute; 0·045 m. drilled per minute; average of six trials. In *serpentine slate*, 260 to 270 blows per minute; 0·066 m. drilled per minute; average of three trials. In *sandstone*, 260 to 270 blows per minute; 0·174 m. drilled per minute; average of two trials. In *gypsum*, 260 to 270 blows per minute; 0·261 m. drilled per minute; average of two trials.	Stapff, "Ueber Gesteinbohr," pp. 87 to 118. Rȥiha, "Tunnelbaukunst," etc., pp. 139 to 152. Zwick, "Neuere Tunnelbauten," pp. 52 to 60.
	II.—NEW STYLE. (Fig. 110.) First used March, 1861, at Bardonnèche, Mont Cenis. (Rȥiha, "Tunnelbaukunst," etc., p. 142.) One small cylinder, s, with fly-wheel attached, for valve motion. Eccentric-wheel n, pawl attached, moves toothed wheel o, which gives rotary motion to square rod fitted into piston of working cylinder. Advance periodical. Rod $t'\ t$ keeps coupling q out of gear until raised by pin on advancing piston; then spring wound around q presses coupling to screw p, and brings about forward motion. Piston moved forward and backward by difference of surface presented to compressed air.	
	III.—LATEST STYLE. (Rȥiha, "Unter- und Oberbau," p. 357.) (Fig. 111.) Valve motion by special cylinder (not given in cut). f presses piston r' inward; piston of working cylinder offers smaller space in front than at back; stroke variable, as with both the former rotary motion of drill by ratchet and pawl at $e\ z'$; forward motion periodical only when p and l coupled, which is effected in the following manner : Variable stroke being exhausted, s is raised, which raises q' and gives piston r a chance to press forward, dragging $q\ q$ (greater part dotted) and with it l forward, coupling l and p, which causes the entire machine to move forward. Wheels h, m, and n for bringing machine back to original position.	
Feb. 13, 1861. No. 373.	**POOLE, WRIGHT, HEMMING and SEARBY.**—The cylinder reciprocates and strikes the drill like a hammer. The piston-rod is stationary, and has steam passages opening into the cylinder ; the piston-rod extends through the lower head of the cylinder, and the socketed end rests upon the drill-head. The upper end of the piston-rod carries a stationary ratchet, into which operates a click for forcing the rotation ; said click being operated by the reciprocation of the cylinder. The cylinder has a spring buffer in the rear end.	

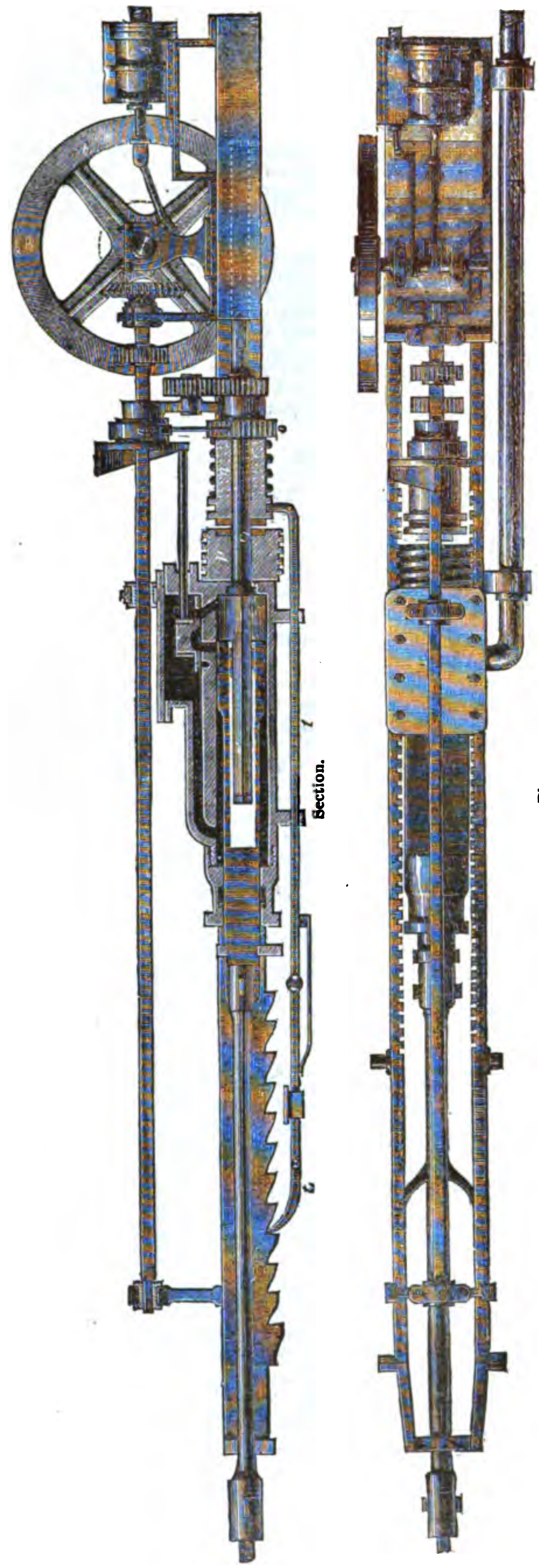


Plan.

Elevation.

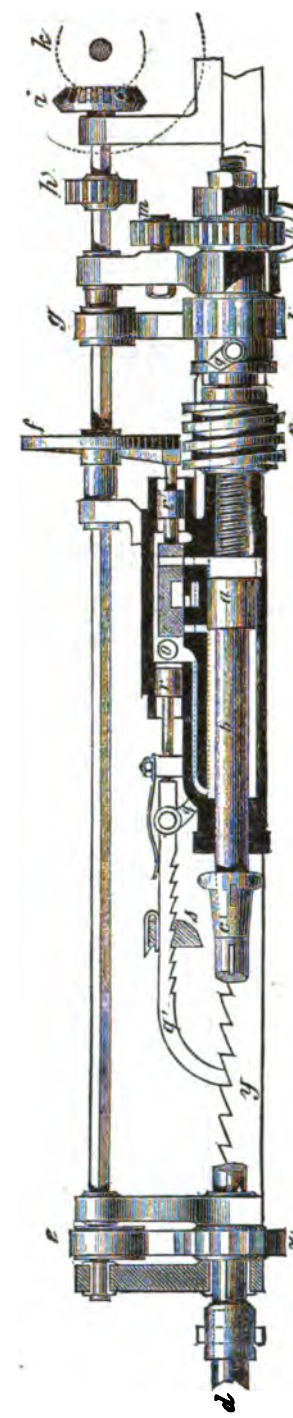
Fig. 109.

SOMMEILLER'S EARLY DRILL.



Section.

Plan.
FIG. 110.
SOMMEILLER'S IMPROVED ROCK-DRILL.



Section.
FIG. 111.
SOMMEILLER'S ROCK-DRILL, LATEST STYLE.

TABLE 23. (*Continued.*)

Date and Number of Patent.	Name of Inventor and Brief of Drill.	Published Descriptions.
Feb. 21, 1862. No. 464.	**E. S. CREASE.**—The valve is operated on down-stroke directly by an annular projection on the drill-bar, and on the up-stroke by a slope on the cross-head. The feed-pawl is attached to the valve-stem, and operated by the same annular projection. Rotation performed by a cam on the valve-rod, which drives a ratchet.	See Mechanics' Magazine, Second Series, Vol. 8, p. 211, Oct. 3, 1862. Article is illustrated.
April 9, 1863. No. 903.	**G. LOW.**—The feed-screw is central, being on the same line as the piston-rod. The rotation is operated by means of a vibrating lever, pawl, and ratchet. Drill was mounted on a carriage, so that it may be moved vertically and horizontally by means of a screw. The carriage was held in place by being clamped against the walls of the tunnel. The drill was mounted on trunnions, which permitted of motion on their axis, and the arm which supported the trunnions had an axial motion, so that universal motion was secured. The valve was operated in one direction by a bell-crank, and in the opposite direction by a spring. The drill was fastened to the piston-rod by a key; Z bits were used.	
Oct. 24, 1863. No. 2624.	**E. S. CREASE.**—The main piston serves as a valve for the piston-valve, there being no metallic connections. A rotating shaft is inserted (for the first time) into the rear end of the piston, so as to rotate the tool. The rotation is performed by a worm-gear, which is driven by the piston-valve, and geared into the rotating shaft. Feed is operated by an eccentric on the rotating shaft, which drives a pawl on the feed-nut. The clamp is on a disc opposite the centre of the slide. This is the first drill operating automatically of which we have any record in which all the devices for operating the valve, feed, and rotation were detached from the piston-rod.	
April 6, 1865. No. 981.	**J. H. JOHNSON.**—Identical with American patent Haupt's drill, 1865, No. 47,819.	
July 5, 1865. No. 1778.	**G. LOW.**—A description of Low's drill and air compressor was published by the Society of Mechanical Engineers, Scotland, in February, 1865. The valve in the earlier drill was operated by a bell-crank, but in the later one it was operated by a spiral bar (which also in some cases effected the rotation) which entered the rear of the piston, and was turned to and fro by the reciprocation of the piston. The feed was automatic. In the earlier drill, the feed-screw was central—*i.e.*, it was placed directly in the rear of the piston, and in a direct line with it. In the later drill, the cylinder which carried the driving piston was entered into another cylinder, and steam was admitted into the last-named cylinder, which constantly tended to force the drill-cylinder forward or out of the former, but was prevented from so doing by means of heavy lugs (called also latches, cams, tappets, etc.), which entered into notches on the frame which supported the drill. When the drilling had advanced so much that the cylinder needed to advance, an annular projection on the piston-bar struck the lugs or tappets, and thus drove them out of the notches, and the steam or compressed air behind the cylinder, as before described, pushed the cylinder forward, and the lugs or tappets caught in the next set of notches. The pressure of the steam behind the cylinder was sufficient to prevent the rebound of the main cylinder. (This mode of feeding has been in use in the Ferroux machine in the St. Gothard Tunnel.) The rotation in the earlier machine was performed by a ratchet, which was forced around by a rocking lever. A flattened part of the drill-bar passed through the ratchet, so that it was compelled to turn with said ratchet. In the later drill, the rotation was performed by a *spiral or twisted* bar, which entered the rear end of the piston, and operated both the valve and rotation. (This is the first record of a spiral bar for producing rotation.) On account of the peculiar feed arrangement, the automatic rotation was complicated. The inventor therefore greatly simplified this part of the machine, and increased its durability by substituting a hand rotation. (He strongly recommended the hand rotation.) A worm-gear engaged a pinion, and the former was turned by hand. The drill was mounted on a *spherical trunnion* opposite the centre of the machine, and admitted of universal movement, so that the drill could be pointed in any direction. The frame on which it was mounted enabled the operator to set the machine in any position. The tool was secured to the piston-rod by means of a nut which screwed into the end of the piston-rod, and was forced against a key which passed through the drill-shank. He used bits of various forms, such as the common bit, the Z bit, and the + bit. The drill was run at 500 to 600 blows per minute; the full length of the stroke was 6 to 7 inches. (This drill was used in Round Wood Tunnel for the Dublin Corporation Works.)	See also "Engineering," vol. i., p. 119, Feb. 23, 1866. This article is accompanied by section drawings, etc.

TABLE 23. (*Continued.*)

DATE AND NUMBER OF PATENT.	NAME OF INVENTOR AND BRIEF OF DRILL.	PUBLISHED DESCRIPTIONS.
Nov. 22, 1866. No. 3065.	**G. HASELTINE.**—See Burleigh's American Patent, No. 59,960.	
Dec. 26, 1866. No. 3395.	**JORDAN & DARLINGTON.**—The valve and feed are worked by hand, by the same crank. The rotation is performed by a spiral bar and ratchet.	
Jan. 7, 1867. No. 48. Also, Nov. 9, 1866. June 7, 1867. ——— Swedish patent, March 5, 1868.	**F. B. DOERING.**—This inventor made a variety of drills, and several different carriages, or frames, for supporting the drill when at work. The valve was a piston driven by steam from the main cylinder, without metallic connections. The rotation was also forced by a piston which pushed a click, the click operating on a ratchet-wheel, said ratchet being attached to a bar which entered the rear end of the piston. The feed was also operated in a similar way. A double click operated upon the feed and rotation ratchets, to prevent them from turning backward. The drill was mounted on a column, said column having an external thread cut the whole length, and forced against the walls of the drift by means of a heavy screw at the end. Two small carriages were used, each supporting a column, which are clamped to the walls of the drifts. These columns carried collars, which were raised or lowered by means of a nut working on the column, or by a pawl working in a rack; there are two horizontal beams attached to the collars, which beams carry the drill.	Description of drill in Stapff's "UeberGesteinb." p. 197. Also, cuts in Stapff, plate 8, Figs. 1–7, 8, 10–12, and 14. See also for Doering's Carriages, "Engineering," Dec. 21, 1866; "Practical Mechanics' Journal,"Apr.,1867, p. 7; "Engineering," vol. vii., p. 354, May 28, 1869; also, p. 113, same vol., will be found cut and description; "Quarterly Jour. of Science," vol. vi., p. 139, Jan., 1869.
Feb. 2, 1867. No. 296.	**E. S. CREASE.**—A spiral bar for rotation. Improved column for tunneling. Same valve movement as in his patent of 1864, No. 2624.	
June 10, 1867. No. 1704.	**FREDERICK BERNARD DOERING.**—The valve was operated directly by steam, without metallic connections. The rotation was performed by means of a pawl driven by a steam-piston, the pawl acting upon a ratchet at the rear end of the machine, said ratchet being attached to a bar which entered the piston. The machine was mounted near its centre on a column which had a screw cut on the outside of it.	
Sept. 16, 1867. No. 2607.	**JAMES ASBURY McKEAN.**—Mounted on two columns joined at bottom. Valve driven directly by a projecting arm on piston-rod. Machine stationary; drill fed by a screw. Rotation by a ratchet in a spiral slot. Successor to the English patent of Haupt's drill. See American Patent, No. 47,819. (For further description, see 1873, No. 2263.)	Cuts of McKean's improved drill will be found in Räiha's "Eisenbahn- Unter- und Oberbau," 1876, Fig. 28, p. 371. Also, see Zwick, "Neuere Tunnelbauten," p. 72.
Nov. 29, 1867. No. 3386.	**JORDAN & DARLINGTON.**—Rotation by two ratchets, having a spiral for one and straight groove for the other.	
April 8, 1868. No. 1183.	**WILLIAM ROBERT LAKE.**—Improvements on Johnson and McKean. Rotary valve (some slight modifications in feed); elastic cushions in the supports.	
June 19, 1868. No. 1989.	**DOERING & TWIGG.**—Well-boring. Machine goes down the hole; the whole is fed by a large screw; the main piston is the valve.	
Sept. 30, 1868. No. 2965.	**F. B. DOERING.**—Feed operated by means of a piston driven by water.	
Aug. 10, 1869. No. 2387.	**EDWARD THOMAS HUGHES.**—Drill mounted by ball and socket-joint; valve moved by a piston; rotation by a spiral bar; feed by hand.	
Nov. 25, 1869. No. 3411.	**THOMAS BROWN.**—Reissue of Burleigh's patent. See English Patent, No. 25, 1869.	
April 14, 1870. No. 1104.	**W. R. LAKE.**—Improvement on McKean's. Rotation. Supplementary spiral wheel. Tool feeds through centre of piston-rod. Rotary valve operated by wing-tappets fixed in the valve-rod.	

TABLE 23. (*Continued.*)

Date and Number of Patent.	Name of Inventor and Brief of Drill.	Published Descriptions.
May 20, 1870. No. 1466. (Tried, 1869.)	**H. OSTERKAMP.**—Piston-valve operated without metallic connections. One of the most novel features is that of performing the rotation by means of a pawl operated by the piston valve.	Described in Zwick's "Neuere Tunnelbauten," p. 50; also, Ržiha's "Eisenbahn- Unter- und Oberbau," p. 368, where will be found cuts also.
Nov. 29, 1870. No. 3131.	**F. B. TAYLOR.**—Improvement on Lake's or McKean's. Instead of a pawl for operating the rotation, a block was used having several teeth to engage in the ratchet on the piston-rod. A feed-click was attached to the valve-rod, so that the feed was operated with each back stroke.	
Oct. 7, 1871. No. 2657.	**J. DARLINGTON.**—Rotation by spiral bar, the ratchet being in the piston; spiral bar also operates valve. Rubber packing at rear end. Piston screwed on to the rod.	
Jan. 17, 1872. No. 143.	**J. G. CRANSTON.**—Valve same as Burleigh's. Rotation by a spiral bar. Chuck same as Hall's American patent. Clamp admits of universal movement.	"Engineering," vol. xxi., p. 87, Feb. 4, 1876.
May 7, 1872. No. 1398.	**F. D. WATTEAU—(DUBOIS-FRANÇOIS).**—The Dubois-François drill is shown in Figs. 112(*a*), 112(*b*), 112(*c*), and 112(*d*). The main valve *m* is	Ržiha, "Eisenbahn- Unter- und

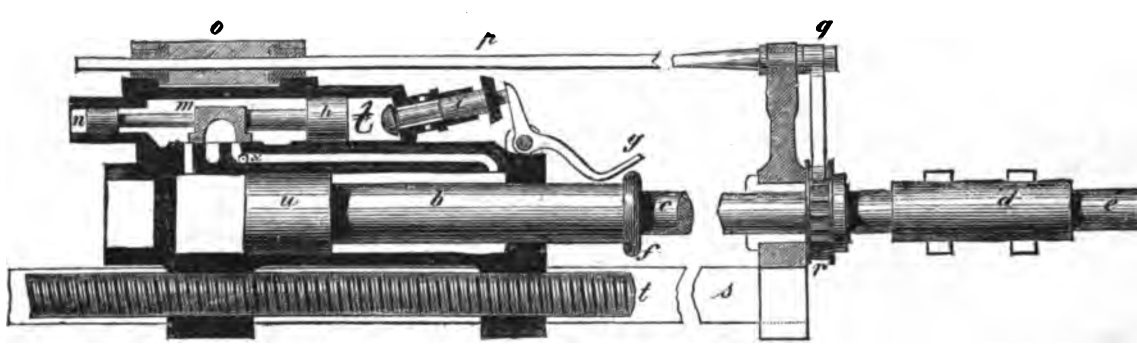


FIG. 112(*a*).

DUBOIS-FRANÇOIS ROCK-DRILL.

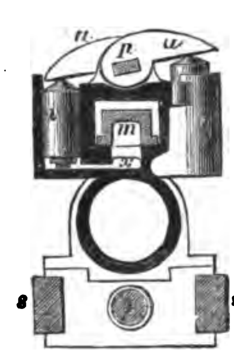


FIG. 112(*b*).

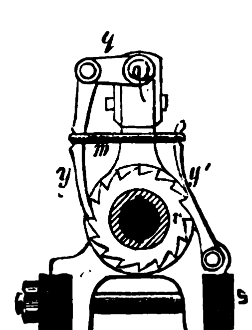


FIG. 112(*c*).

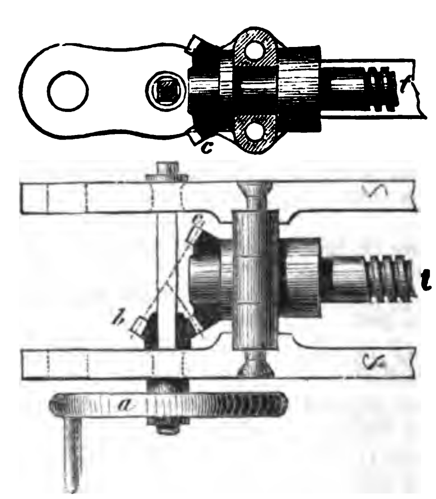


FIG. 112(*d*).

TABLE 23. (*Continued.*).

DATE AND NUMBER OF PATENT.	NAME OF INVENTOR AND BRIEF OF DRILL.	PUBLISHED DESCRIPTIONS.
	moved by the differential piston n h. Near the end of the back stroke of the piston the annular projection f raises the lever g, which forces the poppet-valve i inward, thus permitting the sudden exhaust of the air in the space t, when the pressure of the air on the end n suddenly reverses the valve, admitting the air behind the piston a; and upon the return of the piston the poppet i is closed by the pressure of the air against it, after which the compressed air, which is allowed to pass through a very small hole in the piston-head h, forces the valve in the opposite direction, because the area of the piston b is larger than that at n. These parts are so proportioned that the valve will be reversed at about the same time that the drill strikes the rock. The rotation is performed by means of two pistons, v, Fig. 112(b); a flat bar p, Figs. 112(a) and 112(b); a crank q, Figs. 112(a) and 112(c), on the end of the flat bar p, a pawl y and ratchet r. o is a block on the steam-chest, having arms u u, through which the flat bar slides. Under each arm u is a piston v, one communicating with the steam-passage x, which leads to the forward end of the cylinder, and the other to the other end, so that, as steam or air is admitted to the ends of the cylinder alternately, it will force the small pistons v to be pushed outward, alternately, thus operating the ratchet r. This ratchet has a feather which enters a groove in the drill-bar c. The feed is operated by hand. A crank, Fig. 112(d), connects with a beveled wheel b, and this engages the beveled wheel c on the end of the screw t. The drill-bar c enters the piston b with a slight taper, so that it will hold without a key. The coupling d is secured to the drill-bar c both by taper and key, and the drill e is secured by means of a key in d, as explained in the article on chucks and bits, see p. 174. These drills are mounted on parallel iron bars, s s s (in the several figures), about one inch by two inches cross-section, along which the machine slides. This arrangement is more clearly shown in Fig. 103.	Oberbau," p. 360, cuts 14 to 17. "Engineering," vol. xxi., p. 45, Jan. 21, 1876. Illustrations given. "Iron," vol. iii., p. 104, Jan. 24, 1874. With illustrations. A very clear and good description of this drill is also given, with cuts, in De Bauve's "Manuel de l'Ingénieur," part 12, on Tunnels, p. 22. See also "Rapports Trimestriels de la Conseil Suisse du Tunnel de St. Gothard." "Notice sur l'Installation des Appareils à comprimer l'Air et de perforation aux Charbonnages de la Société de la Marihaye, par Dubois-François, 1873."
July 1, 1872. No. 1980.	**M. A. SOUL.—(SACHS** drill.) The feed is automatic. The feed, rotation and valve are all operated by a bell-crank, which is rocked by the reciprocating movement of the piston. (See next list.)	
July 3, 1872. No. 2008.	**E. LE GROS.**—See Ingersoll's American Patent, No. 112,254.	
Oct. 23, 1872. No. 3125.	**J. H. JOHNSON.—(RAND & WARING).**—Improved tripod.	
Nov. 21, 1872. No. 3491.	**C. J. BALL.**—The main piston forms the valve. These are called valveless machines.	
Nov. 23, 1872. No. 3507.	**BRYDON, DAVIDSON & WARRINGTON.** — Rocking valve operated by a lever between the ends of a double-headed piston, and rotation is made by the same lever.	
Dec. 26, 1872. No. 3921.	**BRYDON, DAVIDSON & WARRINGTON.**—Rack used instead of screw for feeding. Improved tripod.	
Feb. 13, 1873. No. 541.	**E. EDWARDS.**—Valveless. Section of spiral rod is triangular. Ratchet-click for rotating. Is without pins or trunnions, and is placed in a recess in the head of piston.	
April 7, 1873. No. 1280.	**E. EDWARDS.**—Feeds with piston and pawl. The piston is worked by steam from the main cylinder, and regulated by poppet opened by the piston at the end of the stroke.	
April 22, 1873. No. 1455.	**J. G. CRANSTON.**—Valve operated as for Burleigh's. Rotation by spiral rod or by hand, a feather being in the feed-screw. Fed by hand. In tripod all the legs are adjustable. Drill mounted on trunnions.	
May 13, 1873. No. 1734.	**J. DARLINGTON.**—Fig. 113 shows a section of this drill. a is the cylinder, b the piston, and c the rod with spiral grooves for rotating on the back stroke. Steam is in the forward end during both backward and forward stroke. When the piston is forced back of the port at m, steam rushes through the passage to the rear end of the piston, and by the excess of pressure soon stops the piston and causes it to return, striking the blow soon after passing the port m, when the steam exhausts through the hole at o.	See "Iron" for April 1, 1876, p. 421. Full description. Also see pamphlet on "Der Darlington Gesteinbohrer," by Dr. Adolf Gurlt

TABLE 23. (*Continued.*)

Date and Number of Patent.	Name of Inventor and Brief of Drill.	Published Descriptions.
	Drills which keep a constant pressure at the forward end usually strike a comparatively light blow. There are many modifications of the arrangements of the ports in valveless engines. In some, they feed and exhaust in the front of the piston as well as in the rear of it.	(with cuts). Bonn, 1875.

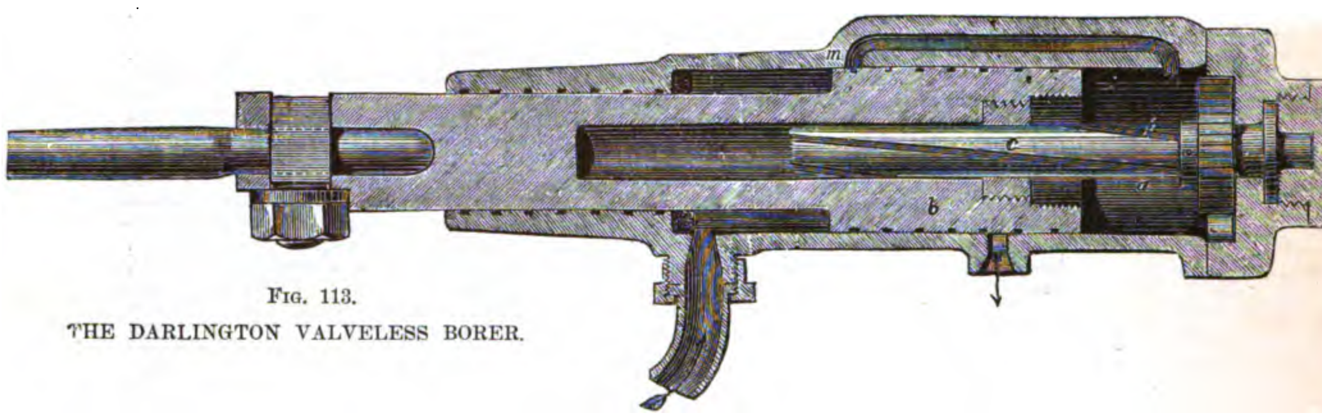


FIG. 113.
THE DARLINGTON VALVELESS BORER.

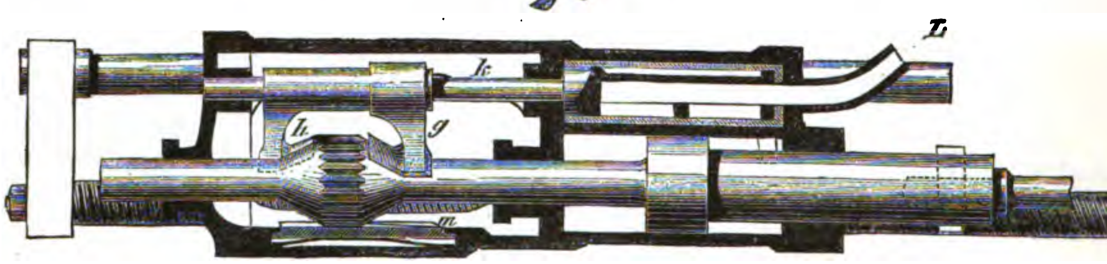


FIG. 114(*a*).
McKEAN DRILL.

FIG. 114(*b*).

Date and Number of Patent.	Name of Inventor and Brief of Drill.	Published Descriptions.
June 3, 1873. No. 1991.	**BRYDON & DAVIDSON.**—Slide-valve worked by arm between the heads of a double-headed piston. Rotation in sleeve at forward end.	
June 30, 1873. No. 2263.	**W. R. LAKE.—McKEAN'S**—Figs. 114(*a*) and 114(*b*)—with rotation at rear end. Improved frame for mounting drill. The McKean drill, so called, is the result of several patents granted under different names: Lake, Taylor, and others. Figs. 114(*a*) and (*b*) are taken from Rživa, "Eisenbahn," etc., p. 371. Compressed air enters valve-cylinder through L. *Valve Motion.*—Oscillating cock. Oscillation produced by annular cam on prolonged piston-rod of main cylinder, striking two pendulums *g h* hanging down from rod *k*, and on opposite sides of the piston-rod. *Rotary Motion.*—Conical part bears teeth like a ratchet-wheel, spirally placed. These teeth, moving along a plate *m* with grooves also placed at an angle to axis of working cylinder, produce rotation. The plate *m* is placed upon a spring. *Advance.*—Automatic, brought about by pendulum *h*, by the rocking motion of which ring *u* is moved forward and backward. This ring has a toothed	Rživa, "Eisenbahn- Unter- und Oberbau," p. 371. Zwick's "Neuere Tunnelbauten," p. 72. "Engineering," July, 1872, p. 42.

TABLE 23. (*Continued.*)

Date and Number of Patent.	Name of Inventor and Brief of Drill.	Published Descriptions.
	edge fitting into a toothed cylinder, pressed against it by a spring, whereby the motion is communicated to the screws. This feed will generally be too rapid, but to set it right the operator has only to turn the crank backward. *Backward Motion.*—For drawing out drill from hole by hand. In the latest form, the operating devices were placed in front of the piston, which is about equivalent to removing the extension *b* and attaching the tool at *f*.	
1874. No. 680.	**G. T. BONSFIELD**—(**FERROUX** drill.)—It is driven by compressed air. The *valve motion* is effected by an oscillating cylinder (Fig. 115) turning a shaft *w* with a fly-wheel attached, and an eccentric *e* on shaft *w* moving the	Illustrations will be found in Rżiha's "Eisen-

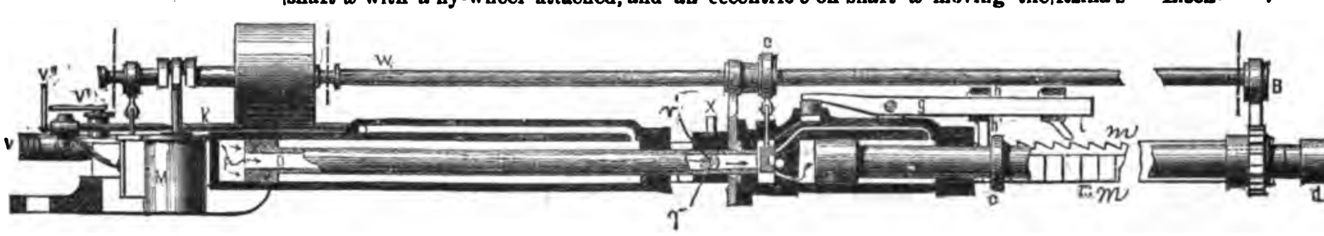


Fig. 115.

FERROUX ROCK-DRILL.

Date and Number of Patent.	Name of Inventor and Brief of Drill.	Published Descriptions.
	sliding-valve (more recently a cock-valve.) The working cylinder is long for the sake of variable stroke. The *rotary motion* of drill effected by ratchet and pawl, moved by eccentric B at end of shafting *w*. The pawl and ratchet are substantially the same as in the Dubois-François. The *advance* is *automatic*. In the long cylinder, called "propulseur," there is a hollow piston-rod *a*, to the back end of which the piston is attached. At the forward end of this piston the entire working cylinder and attachments are screwed. The compressed air entering at P behind the piston of the long cylinder exerts a constant pressure upon it, tending to drive it forward. The air passes continually through the hollow piston-rod, through which it is fed to the valve-box. The check upon this forward motion is brought about by the fork *h* pressing against vertical teeth on the guiding rods or slide. The variable stroke of *a* being exhausted, the ring *c* attached to the piston-rod of the working cylinder *a* strikes the tappet *i*; whereby the lever *g* and together with it the fork *h* is raised. The compressed air is therefore now able to press the piston P forward, and with it the entire front part of the machine. This forward motion is stopped by the sudden return of the fork *h*, forced down by the pressure of compressed air upon a small piston at the other end of the lever *g*. The variable stroke of the piston *a* and the piston P therefore assist one another in automatically moving the entire apparatus forward as the bore-hole grows deeper. A retaining mechanism is necessary at those times when the return motion of the drill takes place, and it is at the same time imperative with Ferroux's system that this retaining mechanism should advance with the rest. To effect this, horizontal teeth are cut also into the guiding-rods *m*. Two horizontal pistons *r r'* catch into these teeth, being pressed against them steadily by compressed air, which is also carried to them through the hollow piston-rod *o*, the whole advancing with it. When it becomes necessary to draw the drill from the hole, the compressed air is cut off from the long cylinder by the valve *v'*. Then compressed air is allowed to act upon the front part of the piston P by opening the valve *v''*, drawing the whole back. In order to prevent the two pistons *r r'* (Fig. 115) from hindering this motion, an india-rubber band is placed around the vertical levers *x x'* attached to them. This drill has been famous on account of its extensive use in the St. Gothard Tunnel.	bahn- Unter- und Oberbau" (Figs. 18 to 21). Description, p. 362. See also "Iron," vol. v., p. 748, Jan. 12, 1875; "The Engineer," vol. xxxix., p. 290, April 30, 1875; "Engineering," vol. xxi., p. 278, April 7, 1876.
1874. No. 1149.	**F. E. B. BEAUMONT.**—Valve is a piston worked without tappets; for rotation, a spiral bar passes into a square mortise in the piston.	
1874. No. 1181.	**WARSOP & HILL.**—Valve operated by a spiral bar. The piston strikes the drill-head. The drill is rotated by hand.	"Engineering," vol. xxxix., p 33, Jan. 8, 1875.

TABLE 23. (*Continued.*)

DATE AND NUMBER OF PATENT.	NAME OF INVENTOR AND BRIEF OF DRILL.	PUBLISHED DESCRIPTIONS.
1874. No. 1603.	**W. MANSON.**—A piston in one cylinder forces air against the drill-piston in another cylinder on opposite sides, alternately. (See Wood's American patent, No. 98,901.)	
1874. No. 1676.	**A. M. CLARK—(CHENOT).**—The drill-piston is in an air-cylinder, and the air-cylinder is reciprocated. (See Bartlett's English patent, 1855, No. 1913.)	
1874. No. 1718.	**J. H. JOHNSON—(WARING).**—See Waring's American patent, No. 178,214.	
1874. No. 2085.	**STURGEON & WHITE.**—Long screw goes through piston-rod for feeding and drill, similar to Brooks, Gates, and Burleigh (American patent, 1866, No. 52,960). Rotary valve.	
1874. No. 2741.	**G. HASELTINE—(THURSTON).**—See Wood's American patent, No. 138,777.	
1874. No. 2760.	**HOSKING & BLAKEWELL.**—Rotation and feed geared together. An annular projection on the middle of piston-rod drives valve. Double piston; clamp double.	
1874. No. 3038.	**H. B. BARLOW—(TURRETINI & COLLADON).**—Hydraulic pressure to feed. Annular piston.	
1874. No. 3342.	**E. EDWARDS.**—Valve driven by piston, which piston is driven by steam from the main cylinder. Fed by piston driven by steam from the main cylinder. Rotation by spiral rod.	
1874. No. 4402.	**F. E. B. BEAUMONT.**—Small trunk engine for valve and rotation. Feed is automatic; feed-click is operated one way by pawl and the other way by a cone on the piston-rod.	
1875. No. 3.	**W. L. WISE.**—Rotation effected by means of a catch contained in a ring or collar.	
1875. No. 485.	**HASELTINE—(WINCHESTER & PHELPS).**—See Winchester's American patents, No. 165,046, etc.	
1875. No. 829.	**F. E. B. BEAUMONT.**—The chief object is to arrange the working parts so that they are readily accessible for cleaning, lubrication, and repair.	
1875. No. 1766.	**BROWN—(BURLEIGH'S).**—See Burleigh's American patent, No. 162,528.	
1875. No. 2013.	**E. EDWARDS.**—Valveless. Peculiar spiral rod, for rotating; peculiar tripod.	
1875. No. 2287.	**G. H. REYNOLDS.**—See Reynold's American patents.	
1875. No. 4207.	**BLAKE.**—See Ingersoll's American patent, July 4, 1876, No. 179,561.	
Jan. 4, 1876. No. 34.	**THOS. LAWRIE.**—Drilling holes in stone paving blocks. Flag-stones are cross grooved, and at the intersection of the grooves, a hole is drilled through the stone by a drill formed of a tube with the larger portion cut away, and the remaining portion set with a diamond. The machine may have solid spindles, as the core drops out.	
Jan. 11, 1876. No. 119.	**JOHANN RICHARD SCHRAM.**—Rock-boring machine. Slide valve rod bears two cylindrical spindle valves, so that the slide valve remains in place without recoil until the piston has made the greater portion of its stroke. Rotation by a small piston at right angles to the main piston, and a cog on which turns the main piston. Slide valve moved by action of team.	
Jan. 20, 1876. No. 222.	**ALFRED, WM.—(TURNER & NEWTON WILSON.)**—Flexible joint for conveying rotary motion. Helical spring fastened to the ends of the shafts to be rotated. (Application is for hair-dressing!)	
Jan. 27, 1876. No. 336.	**ALEX. MELVILLE CLARK.**—Communication from Emil Heyler, Paris, France. Provisional only. Air is transferred from the large cylinder to the small one; the valve chest of the motor cylinder is put in communication with the receivers. The shaft driven from the motor cylinder being made to work a pump by toothed gearing, the intermediate wheel being toothed on only one half its circumference.	

TABLE 23. (*Continued.*)

Date and Number of Patent.	Name of Inventor and Brief of Drill.	Published Descriptions.
Feb. 2, 1876. No. 408.	**ERNEST DE PASS.**—Communication from M. D. Converse, N. Y. Rock-drilling machine. Valve piece has *D* valve at each end, and also bevel tappets passing down into the cylinder and struck by the piston so that when one end of the valve piece is forced laterally, from within the cylinder by the piston, the other end moves laterally into the cylinder. Valve seats are on the inside of the steam chest parallel in line with the valve movement. Valve and tappets are in one piece, and the tappets close the openings into the cylinder. Arm fixed rigidly upon the feed shaft, so that piston can regulate the feed of the cylinder toward the rock. Rotation ratchet is in the head and within the cylinder. Hollow split sleeve attached to the piston rod, with a recess between the end of the piston rod and the sleeve, bored out to receive the drill bar. Two front legs on the tripod are screwed into hips of cast steel; each hip being bored for a screw which passes through it into the saddle, on each side of which last there is a conical recess, in which the hips are drawn firm by the screws. Back leg is forked, and has a spring clamp to surround the saddle.	
Feb. 4, 1876. No. 453.	**ARTHUR & JOSEPH BURDETT.**—(Provisional only.) Air-compressor. There are circumferential openings allowing the air in the cylinder to get into the jacket. Piston made of two heads, having air delivery valves screwed into them. Air is delivered from the cylinder into the hollow of the piston, and this into the jacket. Annular suction valves screwed into the air cylinder covers, and working in time with the piston strokes. Variable steam cut off, worked by the compressed air in the receiver. Circular plate having parallel slot is keyed fast to the crank shaft, and on this plate the eccentric slides transversely on the shaft. On opposite sides of the eccentric is a steel pin which, by a spiral slot, slides around the shaft. Circular motion produced by lengthwise motion on a hard metal sleeve sliding on a screw thread upon the crank shaft. No drawings.	
Feb. 10, 1876. No. 529.	**ANDREW B. BROWN.**—British. Machinery for cutting and getting stone. On each side of the jumper bars there is a pair of smooth wheels held together by springs, and gripping the bars so as to raise them when the wheels are caused to revolve. The periphery of the wheels is not complete, but cut away so as to raise the bars and then let them drop. Bearing surfaces approach simultaneously and let go at the same time. For working horizontally, there is a steam cylinder pressing on the end of the jumpers.	
Feb. 25, 1876. No. 754.	**HERBERT N. PENRICE.**—Rock boring, tunneling, etc. Machine cuts a small hole, which is enlarged before the core is removed. The cylinder which gives motion to the arm and cutting head have a diameter nearly equal to that of the annular groove cut by the head, and the upper part and sides of the bore; this being done by three or more arms fixed to an arm behind the cutting head, each arm bearing a chisel, in the shape of an open ring punch with cutting edges passing across the ring. After cutting some distance the machine is withdrawn, and the holes around the main groove are charged with explosive. The charge holes are closed with three long steel wedges inclined in opposite directions. The charge forces the centre wedge between the other two, being pressed out laterally from the side holes, and vertically from the top hole into the bore. The edges of the cutting chisels are placed circumferentially, and alternately nearer to and further from the centre. The reciprocating cutter head is given rotation.	
Feb. 25, 1876. No. 798.	**JAS. GRAFTON JONES.**—Boring coal, stone, etc. To permit of boring close to the roof, bottom or sides of the working, there is but one worm wheel to feed the drill. The support of the worm wheel is a long tubular bearing equal in diameter to the outside diameter of the feed screw, a portion of one side being cut away to admit a portion of the worm wheel. This worm wheel has a brake race so that its rotation may be retarded. The tool is rotated in one direction at each backward or forward motion of the ratchet lever. In this patent there is also a method of breaking down rock by the means of wedges.	
March, 8, 1876. No. 889.	**GRAHAM STEVENSON.** — Rock-boring apparatus. Compressor, having hollow bed-piece acting as a receiver; over one end is a pair of single acting steam cylinders, and over the other, two air cylinders. Steam cylinders are inclined to each other, so that a cylindrical valve chamber with an oscillating valve may be got between their outer ends; lower ends open into a closed circular chamber in which the cranks revolve. Each passes through outer ends of air cylinders, through spring valves in the piston, into the closed crank chamber.	

TABLE 23. (*Continued.*)

Date and Number of Patent.	Name of Inventor and Brief of Drill.	Published Descriptions.
March 16, 1876. No. 1133.	**HENRY PERCY HOLT.**—Motive power engines. (Provisional protection only.) Compound steam and compressed air engine, having high pressure steam cylinder exhaust into a low pressure cylinder, into which compressed air is admitted from a receiver.	
March 18, 1876. No. 1178.	**WM. ORME CARTER.**—Quarrying stone. Beam fixed against the face of the rock, has guides; and a lengthwise toothed rack is applied thereto, so that a drill carriage may slide along it. Drill axis receives rotation from a toothed wheel on a long shaft running in bearings upon the ends of the beam. This long shaft gets motion by means of a driving rope.	
March 31, 1876. No. 1390.	**FREDERICK E. B. BEAUMONT AND JOS. FOSTER.**—Percussive rock-drills. Improvement on Beaumont's Patent No. 1149, April 2, 1874. Piston valve is hollow, and has perforations in the middle, acting in combination with an annular exhaust passage in the valve casing, in order to serve as the exhaust of the drill cylinder. Drill piston has a lengthwise passage connecting at one end with the atmosphere, and at the other end with the annular recess in the drill piston. Cylinder fed by the piston rod extending through the back head, its end tapering and actuating a wedge piece.	
April 1, 1876. No. 1412.	**EDWARD MADEN.**—Machinery for compressing air. Compressing cylinders operated by electro magnets.	
April 3, 1876. No. 1425.	**JOHN D. BRUNTON & GEO. BRUNTON.**—Tunneling machinery. Cutting head of metal plates, rotated by hydraulic machinery; provided with buckets to remove the débris, which last is carried away by an endless apron. Head is guided by a central steering tube, passage for which is made by a rotating screw cutter.	
May 24, 1876. No. 2189.	**CHAS. J. COPELAND,** Communication from **JNO. B. WARING,** N. Y.—Improvement upon J. H. Johnson's Patent No. 1710 of 1874. Rock-drilling machine. Centrally on the back end of the drill cylinder there is a small force pump driven by the drill piston, and forcing water into the bore hole. For removing the débris from vertical bore holes the spindle has circular steps along its length, and is tapering between the shoulders. Boring tool has two cutting edges upon its face, and cutting edges upon the sides.	
May 25, 1876. No. 2208.	**WM. W. DUNN.**—Rock-drilling machine. Slide valve and ports so arranged that the valve opens and closes the ports by moving laterally on the port face. Valve is operated by the piston rod through a double conical surface thereon, and arms upon the valve spindle. The valve arms may project through the ports into the cylinder. The conical surface on the piston rod communicates motion to a ratchet wheel upon the feed screw. A sounder in combination with the piston rod indicates the necessity of increasing the feed when it is done by hand. Working is stopped when the drill has been run out to the end of the feed motion.	
May 26, 1876. No. 2225.	**JAMES MAWSON.**—Rock-drilling machine. Patent of Nov., 1876 is a better method of doing the same thing.	
May 27, 1876. No. 2233.	**MILES KENNEDY** and **JOS. EASTWARD.**—Rock-drilling machinery. Automatic feed, consisting of a roller, cam and gearing, in combination with a feed screw, nut, and hollow piston rod, giving a rotary and forward motion to the drill bar.	
June 14, 1876. No. 2463.	**DAVID AINSLEY.**—Coal-boring machinery. Screw boring spindle working in a female threaded box, divided lengthwise, so that it may be opened to draw up the spindle. The screw shaft has movement in a vertical arc, and the carriage has motion in a horizontal arc.	
June 20, 1876. No. 2544.	**JOHN D. BRUNTON.**—Machinery for excavating tunnels. Detail improvement upon Patent No. 1784, dated July 5, 1876.	
June 24, 1876. No. 2607.	**JOHN VIVIAN.**—Drilling or boring rock. Diamond drill having vertical tubular boring rod in a bracket, passing through the hollow axis of the bevel wheel; this hollow axis having a feather fitting in a spline in the boring rod. The frame bearing the drill spindle may be moved laterally upon the carriage.	

TABLE 23. (*Continued.*)

Date and Number of Patent.	Name of Inventor and brief of Drill.	Published Descriptions.
Aug. 9, 1876. No. 8150.	**JAS. MACNAB.**—Mining, blasting, etc. Employs in combination with a simple boring apparatus a metallic plug made upon the principle of a breech-loading cannon, and containing the explosive material; this plug being inserted in the hole, and held therein by wedges during the expansion.	
Aug. 14, 1876. No. 8198.	**THOS. FEATHER.**—(Provisional only.) Machinery for compressing air. Two pairs of horizontal cylinders open at one end. All the piston rods are connected with one piston head. Each piston has a valve. At one end of each pair of cylinders there is an air chamber having a valve. When the piston moves in the direction of the air chamber the piston valves are closed. The air from the valve chamber passes by pipes to other cylinders and pistons, valves being provided which let the air back of the piston, and so utilize the force. From this last cylinder the air is forced by pipes into a general receiver. The first mover is a steam engine.	
Sept. 25, 1876. No. 3741.	**GUSTAV HEINRICH NEUMANN**, Philadelphia.—Boring or drilling rocks. Boring bit has double cutting surface. The rod is raised, turned, and fed forward at each action of the cam.	
Oct. 19, 1876. No. 4045.	**JOHN DARLINGTON.**—(Provisional protection only.) Percussive rock boring machine. Outer surface of the cylinder is screwed to permit of feed. Pressure is introduced through a revolving joint so that the cylinder may be rotated. Feed by means of a lever struck by the piston.	
Nov. 2, 1876. No. 4537.	**JAS. MAWSON.**—Machine for drilling coal, rock, and stone. Drill rod is screwed upon its upper end, to correspond with a cylinder in which it is screwed up. This cylinder, being given a firm abutment, is turned by a ratchet, and thus forces out the screw and the drill.	
Nov. 11, 1876. No. 4871.	**FRANK WORTH**, Frankfort on the Main, Germany.—Apparatus for controlling the dip, etc., of borings. The dip of the boring hole is controlled by a glass half filled with dilute fluoric acid which will etch the sides of the glass tubes and show the dip. The bearing is controlled by the mariners' compass with a freely balanced needle, which at a certain time is raised whilst the parts are in the hole.	
Nov. 21, 1876. No. 4523.	**ALFRED V. NEWTON.**—Air pumps. Combination of an air-compressing piston arranged to pass in its delivery stroke beyond the face of the seat of the outlet valve; air inlet valve of approximate area with the piston, and outlet valve which covers or laps over the delivery end of the bore of the cylinder; this outlet valve and piston being faced to make a close joint with each other throughout the area of the piston. Enlarged chamber at the delivery end of each cylinder of the compressor, and constituting a seat for the outlet valve. Pressure-limiting device controlling the motive force.	
Dec. 4, 1876. No. 4682.	**W. R. LAKE**, Communication from **ALFRED BRANDT**, Hamburg, Germany.—Hydraulic machinery for boring rock. Slightly conical toothed steel boring tube, screwed to hollow boring rod. Pressure given by movable hydraulic cylinder sliding and rotating on a fixed piston. Abutment against hydraulic press, jamming the sides of the cutting. Rotation by two hydraulic engines.	
Dec. 18, 1876. No. 4818.	**JOHN SHAW.**—Operating air-compressing valves. Provisional protection not allowed. Operating valves by a hydraulic apparatus, comprising a cylinder attached to the piston rod of the compressor, the piston rod of this cylinder being attached to a cross-head to which the valve spindles are fastened. Valves are moved by steam cylinder and piston; or, valves operated by eccentrics.	
Jan. 12, 1877. No. 162.	**WM. WYNN KENRICK**, Birmingham. Communication from **WM. WEAVER**, Phœnixville, Pa. (Provisional.)—Rock-drill. Drill end is in the form of a double gouge or V. Drill mounted on frame having frictional clamp combined with a ratchet nut holding drill as it is raised and turned. Nut in descending strikes a step allowing the drill to be fed forward. Rotation of drill regulated by adjustable fingers fastened to driving cam.	
June 26, 1878. No. 2572.	**THOMAS BROWN JORDAN** and **THOS. ROWLAND JORDAN**, London.—Pneumatic and hydraulic machine for drilling rocks, crushing ores, etc. Improvement upon T. B. J., Feb. 2, 1877, No. 440, and Sept. 18, 1877, No. 3510. Cylinder of rock-drill is provided with means of taking small additional charge of air at every stroke of the piston. Increase of pressure is provided against by escape valve. Portion of piston rod below piston is enlarged to nearly diameter of piston. Rod passes through gland at bottom of cylinder,	

TABLE 23. *(Continued.)*

Date and Number of Patent.	Name of Inventor and Brief of Drill.	Published Descriptions.
	packed with cup leather turned upward to admit air during up-stroke, and the piston is packed so that this air passes up to the space above the piston. This gives the dead blow. Cylinder has air-tight piston and tubular rod through which the boring rods pass, and to which they may be clamped while working. Piston and rod are rotated by suitable gearing, and cylinder is in connection with hydraulic pump on the slide valve, so that pressure may be thrown on either side of the piston at will. This patent claims the power of boring by rotation or percussion with the same kind of machinery. Piston is driven by the force of air compressed behind the piston; piston being raised by the revolving cam; driven by hand or otherwise.	
Feb. 14, 1877. No. 619.	**JNO. SHAW** and **WILLIAM TIMBREL CLARK**.—Machinery for boring rock. (Provisional.) Cylinder and piston rod with two pistons thereon. Steam introduced into the middle of the cylinder acts on one or the other of the pistons, closing the exhaust, and forcing the steam or air from one piston to the other, by one of the pistons coming into contact with a slide valve. Automatic feed by small cylinder affixed to the side of the main cylinder; steam or air passes from the large cylinder into this and acts upon catches and wheels; or, steam or air may be let into the middle of the slide valve, using the space between the two pistons for exhaust.	
March 21, 1877. No. 1126.	**CHAS. SPRUYT DE BAY**, 9 Victoria Chambers, Victoria St., Westminster.—Apparatus for giving movement or power to liquids, air, or gases. Striking or pressing the air or other liquids or gases at the same time and within the same space comprised between two similar planes perpendicular to the axis of the apparatus, by the combined action of surfaces placed at an angle with the side axis. Prefers helicoid surfaces; using blades of two screws, one right and the other left handed, revolving on the same axis in contrary directions, entirely or partly within two planes perpendicular to the axis, so that they shall work within one another, and not beside or behind one another.	
March 26, 1877. No. 2054.	**PHILIP JOHN LEGROS**, 4 Queen's St., Southwark Bridge.—Rock-drill. (Provisional only.) Valve motion and feed are by a single double-ended lever worked by the piston, and brought back by two springs, or by two small pistons acting upon a projection on the lever shaft or on the lever itself. Distribution of motive fluid by two pistons inside cylinder, or by one or two slide valves. Motion of double-ended lever regulated by shape of groove in piston. Rotary and feed ratchets are upon the principle of friction wheels; one being a grooved cylinder, and the pawl being part of another cylinder fitting these grooves, and turning around an axis so placed as to release all friction when ratchet turns in one direction, and increase it when direction is reversed. Chuck has a collar protecting the bottom of the piston from blows, and carrying screws acting upon a steel piece holding the bit. Machine is fixed in a split hinged clamp collar carrying the cup receiving the drill.	
March 29, 1877. No. 1245.	**THOS. WARDLE ASQUITH** and **RICHD. DONALD BAIN**.—(Provisional.) Boring machinery for mining. Boring shaft passes through and is supported within axle of a chain wheel carried by a carrier, and driven by a smaller wheel upon the same carrier. Motion may be given to the latter wheel by a winch handle, and transmitted by an endless band or chain. Boring shaft has two key ways along its whole length, into which fit loosely two keys from the interior of the hollow axle of the first wheel, so that when this rotates the boring shaft does. Fed by a box nut on the inner side of the carrier, also forming an abutment to receive the thrust of the boring tool.	
March 29, 1877. No. 1247.	**JOHN TWEEDY**, Sunderland, Durham.—Drilling machines. Main upright has a guide of the form of a sector of a ring, to keep the drill radial. Arrangement of wheels and sliders, by which a revolving shaft with lengthwise axis fixed with regard to the main upright in a direction parallel or nearly so to the chord of the arc described by the saddle in its traverse over the circular guide, may drive the drill spindle, the position or direction of which varies in the same or in a parallel plane. To drill holes radially in circumference of cylindrical bodies. Article to be drilled is supported on wheels.	
April 16, 1877. No. 1485.	**WILLIAM WALLACE DUNN**, San Francisco, Cal.—Rock-drill. To prevent drill edge wearing away, drill end has wings or projections upward from the cutting edges, so that they form a support and guide.	
May 3, 1877. No. 1724.	**ALFRED UPWARD**.—(Provisional.) Boring apparatus for rescuing entombed miners. Drill passes through a packed gland in the centre of a hollow chamber fitting tightly on a cylinder. On the side of this cylinder there is a	

TABLE 23. (*Continued.*)

Date and Number of Patent.	Name of Inventor and Brief of Drill.	Published Descriptions.
	slide valve moving across the cylinder after the hole is made through the coal, and the drill brought up into the hollow chamber. Just below slide valve is flange to make tight joint between chamber and face of coal or rock, by a soft packing.	
May 19, 1877. No. 1965.	**WILLIAM ROBERT LAKE**, Communication from **EDWARD STEVENS WINCHESTER** and **HARVEY CLAPP FLAGLER**, Boston, Mass.—Rock-drills. The main cylinder has an exterior screw thread in a spherical holder fastened to the column, thus dispensing with the feed screw. Holder is held in a clamp or socket. Cylinder turned by a ratchet and an eccentric and the shaft rotating the piston. Pawl is pivoted to a bar sliding through the holder through which the cylinder is fed. Motive fluid is introduced into the cylinder through hollow collar connecting with steam or air passages in the cylinder head, and moving lengthwise with the cylinder, but not rotating with it. Rear end of the cylinder has a shoulder against which the cylinder head is tightly pressed by a sleeve screwed into the front of the cylinder, and having several sleeves and rings between them to hold the cylinder head rings and sleeves in place. There are buffers in an extension of the cylinder and outside of the steam cylinder. Buffers are elastic rings having a metallic partition between them.	
July 11, 1877. No. 2675.	**WILLIAM ROWLES**, Rickmansworth, Herts.—Apparatus for boring wells. Wrought iron cylinder divided by a partition into two chambers, the upper to contain the mechanism, and the lower the débris. The lower end has a circular rim larger than the cylinder, and containing boring tools. This end has an india rubber valve allowing the débris to rise fast. Boring chisel is fixed in bayonet slots. Apparatus is jumped at the end of a rope attached to a swivel by clutches, and the torsion of the rope causes partial rotation of the whole.	
July 20, 1877. No. 2774.	**EDMUND EDWARDS**, 40 Southampton Buildings, Chancery Lane, London.—Rock-drills and air-compressors. Annular grove in the piston rod, with tapering edges. There is a small supplementary cylinder having three ports, of which the two outer ones open into the main cylinder and the centre with the supply of motive fluid. Inside the smaller cylinder there is a slide valve, driven by a bar against its back, and having at each end an opening fitting the outer ends of two bell crank levers with their inner ends projecting into the main cylinder. These levers are actuated by the inclined edges of the groove in the main piston. Two compressing cylinders, side by side, are open at their upper ends. Each has a piston, and sets in a cistern of cold water, the water being at such a level that when the piston is at the bottom of its stroke the water will enter the cylinder above it. Between the two cylinders there is a 4-way cock, two ports opening it into the lower ends of the two cylinders, one to a pipe through which the motive fluid is supplied, and the other to the delivery pipe. The plug of this cock is connected to the revolving driving shaft, so as to make one revolution while the driving shaft makes two.	
July 26, 1877. No. 2863.	**AUGUSTE ALEXANDRE GOUBERT** and **NATHANIEL WATERMAN PRATT**, Brooklyn, N. Y.—Rock-drill. Piston has variable area upon opposite sides; live steam acting upon smaller side for working blow; exhaust being discharged at the next working stroke. Automatic friction feed. Telescopic lug with clamp and key. Weights supported upon the lower joints of the tripod by adjustable collars with lateral stems receiving set screws. Trunk piston and tappets. Valve has yielding spring stop. If piston overruns, valve motion opens live steam port and cushions piston. Feed tappet gives quick motion during latter part of every working stroke, and second tappet gives slower motion in the opposite direction to advance bit during return stroke, this feed being determined by the depth to which the tool at the preceding blow has penetrated the material.	
Aug. 28, 1877. No. 3272.	**JOS. ROSEBY** and **WM. BALMER**, Newcastle on Tyne.—Boring machine. (Provisional.) To drill several holes contiguous and in line. System of gear wheels rotates four boring tools in a horizontal line. Above the centre of this line one boring tool drills a hole for blasting charge. Near their	

TABLE 23. (*Continued.*)

DATE AND NUMBER OF PATENT.	NAME OF INVENTOR AND BRIEF OF DRILL.	PUBLISHED DESCRIPTIONS.
	drill points the tools are connected by a "combiner" to prevent them swerving or from clashing.	
Sept. 18, 1877. No. 3510.	**THOS. BROWN JORDAN,** Queen Victoria St., London.—Pneumatic drill. Improvement on Patent 440, Feb. 2, 1877. Feed by screw on the upper part of the drill bar; and fitting on the latter, a long nut free to turn in the lifting block. The upper part of this nut slides the length of the stroke to answer through a miter wheel turning upon the nut. This miter wheel is operated by another miter wheel on a shaft with the hand wheel. The lift block and tool bar are turned by a cam as described in the former specification. If the nut wheel is clamped by the nut the tool bar is fed on, and the rate of feed depends upon the amount of clamping	
Oct. 23, 1877. No. 3921.	**JNO. DRYSDALE** and **RODERICK WALTER BAYNES,** Millbank, Plymouth, and **MR. JNO. SNAWDON STONEHOUSE,** Devon.—Multiple drill. (Provisional protection only.) At the upper ends of the spindles there are crank arms inclined to the spindles, and all inclined in the same direction. These crank pins are parallel with the spindles and enter holes in a disc having circular motion from a crank, without rotation. Rotation of the driving crank rotates all the drill spindles.	
Oct. 30, 1877. No. 4027.	**ERNEST DE PASS,** Fleet Chambers, London. Communication from **ARVID HENRY ELLIOT,** N. Y.—Percussive rock-drills. (Provisional protection only.) There are but two movable pieces, valve piece and piston. Ordinary D valve is made circular, and has at each end a piston turned to fit the valve box and having a guide to prevent turning around. Valve box has exhaust ports for the valve piston, carried across and to opposite ends of the box and leading into the steam cylinder. Valve box has rubber cushions at each end, protected by steel plates. Rotation is by a fluted bar.	
Oct. 30, 1877. No. 4033.	**THEODORE FRÖLICH,** 26 Fenchurch St., London. Communication from **JULIUS FRÖLICH,** Dusseldorf.—Percussive rock-drills. There is a slide valve fixed between two pistons received in corresponding cylinders connected by a passage with the main cylinder. Each valve cylinder has a vent to let the air escape when the connection with the main cylinder is cut off; the size of these vents measuring the speed of reciprocation of the main cylinder. Feed automatic by a screw and nut, having ratchet teeth. Rotation by fluted bar having ratchet clutch head engaging with a clutch upon the head of a plunger or ram worked by compressed air.	
Nov. 17, 1877. No. 4316.	**JOHN ALBERT REINHOLD HILDEBRANDT,** Communication from **FREDERICK PELZER,** Dortmund, Germany.—Percussion rock-drill. (Provisional protection only.) Ordinary D valve, rod actuated by two levers centered near the end of the piston rod; when near the end of its stroke, one end moving freely in a slot in the rod, the other coming in contact with a nut on the piston rod. There are buffers at each end of the valve chest. Feed and rotation of tool by a side lever having a crank end working in a slide to which are attached the clacks turning the ratchet wheels; one sitting on a square rod working into the piston rod, and the other fixed on the nut of the feed screw. Crank lever is pressed by a spring and slides upon the piston rod. Bore is cleared by water passing through a groove or passage in the stem of the tool shaft, which last passes through a reservoir of water.	
Dec. 20, 1877. No. 4841.	**JAS. KERGULLAND,** Wesminster Palace Hotel, Victoria St., Westminster.—Diamond boring. The diamonds are set in steel plugs or holders, aided by solder, pins, or screws. This can be used in crowns or bits of different sizes. The diamonds are set in separate rings adapted to the crown of the tube, and set by forcing into taper holes in these rings or in the plugs. Cross-head is guided in its vertical motion by two pillars, one of which admits one end of the cross-head turning upon it, and the other has a guide surface; one end of the cross-head will be free of that pillar, while the other may turn upon the other pillar, thus clearing the drill from the line of the hole. To retract the drill bars or lining tubes there is a hydraulic cylinder with an annular space with a corresponding ring piston. The adjustment of the counter weight to the boring rod may be varied, by having the chain or band which supports the drill rod connected to and wound on a drum to which there are several wheels of different diameters and speeds. Speed of drill regulated by a hydraulic brake. The	

TABLE 23. (*Continued.*)

Date and Number of Patent.	Name of Inventor and Brief of Drill.	Published Descriptions.
	crown or bit is formed as part of a turbine wheel, set in motion by water sent down tubular rods.	
Jan. 21, 1878. No. 271.	**JONATHAN HARRISON**, Coalville, Leicestershire.—Wedging apparatus for breaking down coal. Two grooved metal pieces or feathers. A combined metal wedge, circular in cross section in front, circular and rectangular in the middle portions, and in cross section in the back portion. The two feathers are placed in the wedge hole in the coal and the combined wedges driven in.	
Jan. 23, 1878. No. 764.	**WALLACE DUNN**, San Francisco, Cal.—Rock-drill. Valve consists of a valve proper on the carrier in a case, arranged across the cylinder. Valve is moved by steam pressure on the ends of the carrier, which are fitted as pistons in the cylinder casing. Valve is half round and adjustable for wear. There is a pusher to act as a starting pin used by the attendant to warn attendant when feed requires adjustment, there is a pulse piston; the small cylinder along side of the main cylinder having a piston with a rod arranged to ring a bell when the drill requires feed. When the drill is being fed the bell's piston will not be moved, but when the main piston of the machine is driven too far, ports will be uncovered by it and the small piston given to and fro motion. There may be an automatic feed mechanism at the side; the case within which is a cylindrical valve moving therein, and working the lever on a rod at right angles to it. Cutting edges of the bit converge. Column bears a chain passing over the sheave at the upper end of the pillar, to facilitate raising the machine. There is a rotating coupling box having a projecting arm from each side, each having a box coupling with two apertures in its face, from a trunnion upon the machine. Rotation a slight improvement upon that obtained May 25, 1876, No. 2208.	
Feb. 14, 1878. No. 629.	**ERNEST DEPASS**, London. Communication from **HENRY ELLIOT**, N. Y.—Percussive rock-drill. A valve moves upon a rod or belt within its valve box, having a guide to prevent valve from turning. Exhaust steam or air from opposite ends of the valve may be controlled by a groove or recess in the main piston. Valve controlled by exhaust steam or air from opposite ends of the valve box, without any connection with the steam or air in either end of the main cylinder. Rotation feed by fluted bar, and screw automatic feed of cylinder by spring and pawl forcing feed nut to revolve upon the feed screw when piston in its upward stroke is out of contact with the beveled projection upon the shaft. Tripod having two lugs from the body of the machine and one from a yoke above the pack head, and bearing the feeding screw nut.	
May 16, 1878. No. 1973.	**JNO. ALBERT REINHOLD HILDEBRANDT**, Manchester. Communication from **FREDERICK PELZER**, Dortmund, Germany.—Rock-drill. Slide valves worked by tappets tripped by a boss upon the piston rod. Valve chest has buffers. Tool turned and drill fed by side lever, with crank end working in a slide to which clacks are attached turning ratchet wheels. One of these sits upon a square rod working into the piston rod, the other is fixed upon the nut of the feed screw. This crank lever is pressed by a spring upon the same boss which moves the slide tappets. To remove the bore dust the cylinder cover is formed into an annular casing, and the piston rod has an internal passage running from the socket and opening into the annular passage. The drill has an internal passage opening near the cutting edge. The annular chamber is supplied with water by a flexible tube.	
May 18, 1878. No. 1944.	**GEO. FORSYTH**, Lancaster, and **EDMUND BARNES ULVERSTON**, Lancaster.—Percussion drill. Central feed screw is hollow, to convey the motive fluid. Cylinder is in a hoop connected to a tripod and to a cross-head carrying the nut for the feed screw. Cylinder and piston rod turn together, and are fed forward together. Piston rod has a hollow back continuation. Slide valve tappet is operated by a boss upon the piston rod. Legs are telescopic, and have feed steps for the attendant to stand upon.	
May 30, 1878. No. 2165.	**JNO. BROWN, SR.**, 13 Rawlinson St, Dalton-in-Furness, Lancaster.—Rock-drill. Piston and rod in one solid piece, with side grooves at the ends of the piston. Spring ring around the piston rod, working to and fro along with it, dispenses with a stuffing box. There are three ports in the cylinder for admission on the inlet side, and two on the outlet side. Pistons are driven to	

TABLE 23. (*Continued.*)

DATE AND NUMBER OF PATENT.	NAME OF INVENTOR AND BRIEF OF DRILL.	PUBLISHED DESCRIPTIONS.
June 26, 1878.* No. 2572.	and fro and turned by compressed air acting upon or in the grooves at the ends. Pistons act as a valve. Motive fluid enters at a tangent, turning the piston.	
June 28, 1878. No. 2598.	**MARTIN MACDERMOTT**, Scotts Chambers, Pudding Lane, London, and **GEO. WM. ELLIOT**, Altrinchaw, Cheshire.—Drill turned and fed by some mechanisms. Incline for a ratchet may be set to any angle to vary the feed. If set to feed faster than needed the drill bar stroke will be lessened, and consequently the length of the incline along which the ratchet lever travels. Drill bar nut is peculiarly split to form withdrawing drill without unscrewing. Body of the machine attached to frame or legs so that it can be turned around the axis of the driving shaft to any angle without moving the frame or legs.	
July 5, 1878. No. 2696.	**CARL PIEPER**, Dresden, Saxony. Communication from **JACOB FABER**, Barmen, Prussia.—Hand rock-drill. Driving cam bears a cam disc. Collar upon the drill spindle bears upon the cams; drill is driven forward by the compression of a spring. Drill rotation is given by having the spindle square in section, and twisted, passing through the nut, which is split so that it may be opened to draw back the drill without running it back slowly. Drill feed is in the operation of raising drill; screw thread upon spindle being cut so that by turning the collar with the nut, drill is advanced. Frame is universal.	
July 29, 1878. No. 3012.	**PETER JENSEN**, 33 Chancery Lane, London. Communication from **LUDWIG SCHRADER**, Essen, and **JOS. FRITZ**, Suelz-bei-Koln.—Hand rock-drill. Crank and gears work a cam against a bar or friction roller in the end of a forked bracket. There is a volute plate spring.	
Aug. 15, 1878. No. 3222.	**RAPHAEL HUNTER BRANDON**, 38 Southampton Bridge, London. Communication from **LEOPOLD TASKIN**, Liege.—Tunneling horizontally by compressed air. To prevent the compressed air introduced in the working cylinder from escaping from the upper end of the cylinder, the head of the working cylinder is closed by a shield divided in two parts, one at the upper part at its outer edge, and descending vertically below the level of its axis, and the other further back within the cylinder, and rising diagonally from the bottom to above the axis. Any water in front of the working cylinder can enter the latter only.	
Oct. 18, 1878. No. 4152.	**ERNEST GUSTAVUS REUSS**, Manchester.—Drilling holes in coal or rock. To drill holes with great accuracy in coal, the drills have cutting edges intended to cut off a shaving like the plane iron. Four holes, one to two inches diameter, the cutters may be in the form of two wings projecting from the stem with their edges set forward in the plane of rotation, front sides sloping back from the edge, and their hinder sides rounded off obliquely to give ample clearance. For larger drills the cutters are set in slots in a head. Large drills may have in the front of the head a starting drill, although it is preferred to use the smaller drill with cutter wings. For deep holes the long stem is made of short lengths screwed together. The short drill is run in to its full depth, then the stem is unscrewed, leaving it in the hole, and the next length is screwed on, and the boring continued and so on. To steady the machine there is a strong disc with set screws, and having through its middle the screwed stem with a nut. On this stem are tapered grooves with greatest depth toward the front end of the stem. In each groove is a key with a keep head. Boring the holes say one foot deep, this screwed stem is inserted, the key driven, and the face plate tightened by the set screws. The drill machine is fastened to this stem by a universal joint.	
Oct. 31, 1878. No. 4396.	**EDWARD JONES**, Caerphilly, Glamorganshire.—Drilling holes for blasting. Void for informality. Utilization of the streams of water which flow down the sides of mountains and quarries, in driving turbines by which drills are driven.	
Jan. 10, 1879. No. 104.	**HENRY RICHMANN** and **URIAH KLINE ARNOLD**, San Francisco, Cal.—Direct acting engines and drilling apparatus. Piston contains valve concentric with itself, and reciprocating motion in same direction with piston. Tripod legs are screw threaded and extensible. Cylinder rotates with drill.	

* This description was misplaced by accident, and will be found on page 287.

TABLE 23. (*Continued.*)

Date and Number of Patent.	Name of Inventor and Brief of Drill.	Published Descriptions.
March 8, 1879. No. 923.	**TOM BELLINGHAM,** Docwra, Islington.—Steadying rock-drills. (Provisional only.) Drill bar, core tube, and after part of crown have tubular guides with adjustable springs bearing against sides of hole.	
May 7, 1879. No. 1809.	**JAS. A. GULLAND,** 6 Victoria St., Westminster.—Diamond drill. Drill bar is supported in bearings, one of which is movable on a bed or frame, and is operated from the boring rod by spur gearing, worm, and worm wheel, and a rack pinion for the feed. Axis or shaft may rotate independently of the worm wheel, so that drill may be drawn back quickly. Hollow drill bar for carrying water to wash out hole, supplied by pliable pipe between rolls. For undercutting the drill has a tube with slots, furnished with latches, armed with diamonds, and hung on pins, so that they may be thrown out by water pressure.	
June 7, 1879. No. 2258.	**CARL PIEPER,** 74 Belle-Alliance Strasse, Berlin, S. W. Prussia.—Hand rock-drill. (Invention did not proceed to a great sale.) Improvement details of Patent No. 2696: May 5, 1878.	
June 24, 1879. No. 2258.	**WM. LOWBER NEILL,** London.—Percussion rock-drill. (Provisional only.) Piston, with upper portion smaller than the lower, is inclosed in cylinder with interior corresponding in diameter with the piston. Motive fluid enters smaller cylinder continuously through inlet port, whence it passes by an air induction passage in the upper end to the lower end of the larger cylinder. This induction passage is opened and closed by smaller piston, and motive fluid does not enter therein until piston has made most of its forward stroke. Exhaust opening from the larger cylinder is controlled by larger piston. External air is drawn through the side of larger cylinder for an air cushion.	
Oct. 10, 1879. No. 4097.	**JNO. IMRAY,** 28 Southampton Bridge, London. Communication from **CHAS. WM. BURTON,** Paris.—Percussive hand rock-drills. Raising piston compressing air in cylinder above it. Leakage counteracted, down stroke cushioned, by enlarging lower part of piston rod to form a trunk with annular spaces around it, into which air enters through check valve during up stroke. Key is inserted to prevent piston rod from turning when drill is turned out by hand.	
Nov. 1, 1879. No. 4455.	**MAX BLUMENREICH,** Berlin.—Hydraulic rock-drill. (Provisional only.) Cutter or boring tool is operated by the disc or water wheel directly over the part to be bored. A portion of the water is used to force out the débris. Driving parts placed inside a tube which follows the cutters.	
Nov. 3, 1879. No. 4472.	**CHARLES LOUIS LACARRIERE,** Paris.—Digging, picking, or boring the earth. Carriage bearing revolving picks upon horizontal shafts, which dig out the earth, dropping it upon an endless apron.	

TABLE 24.

Carriage List.

1863 and 1865.	**LOW'S** carriage is described in his patent above, p. 278.
1867.	**DOERING.**—Described in patent above.
Sept. 17, 1872. No. 2756.	**SHEPHERD & STUCKEY.**—Frame, etc., for mounting drills.
1874. No. 1278.	**BRYDON & DAVIDSON.**
	BARTLETT.—There is a cut of a carriage proposed by Bartlett to accompany his drill, in Stapff's "Ueber Gesteinbohrmaschinen," Plate II., Figs. 5 to 7.

TABLE 25.

OTHER EUROPEAN ROCK-DRILLS NOT INCLUDED IN THE ENGLISH LIST.

DATE AND NUMBER OF PATENT.	NAME OF INVENTOR AND BRIEF OF DRILL.	PUBLISHED DESCRIPTIONS.
France, Oct. 15, 1851.	**CAVÉ**, at Paris, constructed a rock-drill worked by compressed air. (See Fig. 83 and description, p. 195.)	See Ržiha, "Eisenbahn- Unter- und Oberbau," p. 351. Also Stapff, "Ueber Gesteinbohrmaschinen," p. 53, and Pl. I., Figs. 25 to 29. Stapff's authorities on Cavé are: Armengaud's "Génie Industriel," 1852, p. 129; Dingler's "Polyt. Journal," 1852, p. 327; "Bulletin de la Société d'Encouragement pour l'Industrie minerale," 1863, No. 132; "Berg u. Hüttenmännische Zeitung," 1864, p. 147.
Saxony, 1854.	**SCHUMANN.** (Fig. 82.)—This machine is automatic	Stapff, "Ueber Gesteinb.," p.132.
Feb. 17, 1857.	Percussion machine, compressed air. Valve, four-way cock, by hand. Rotary motion. Thread on fly-wheel shaft working in gearing on piston-rod. (See Stapff, pp. 132 to 145, Plate V., Fig. 1.)	Stapff, "Ueber Gesteinbohr," pp. 132 to 145. Stapff's authorities on older constructions are Gerlach, "Jahrbuch für den Berg und Hüttenmänn.," 1861, p. 206. Later construction: Sjoegren, "Jernkontorets annaler," 1863, p. 363.
Saxony, Feb. 1, 1860.	Percussion drill. Valve sliding by hand. Rotary motion by screw on fly-wheel shaft. Advance by hand, special crank. (See Stapff, Plate V., Fig. 2.)	
Tried but not patented, 1862.	Automatic machine. Valve motion by special auxiliary cylinder. Rotary motion by screw on fly-wheel shaft. Advance by hand. (See Stapff, Plate V., Fig. 31.)	No carriage for first drill. (See also Ržiha, "Tunnelbaukunst," pp. 133 to 135.) Later a wooden carriage used (see cut, Stapff, Plate IX., 4*a* and 4*b*).
April, 1862.	**CASTELAIN.**—Both Ržiha and Stapff take from Devillez, "Des Travaux de Percement," etc., p. 244. Drill pressed upward by a cam on shaft turned by steam-engine. Drill forced downward by powerful spring; 90 to 100 blows per minute; lift, 0·10 m. high; hole drilled per minute, 0·025 m. deep.	Ržiha, "Tunnelbaukunst," etc., p. 133. Stapff, "Ueber Gesteinbohr," p. 48.
	MARCELLIS.—Stapff takes his notes of this drill from the "Annales des Mines," 1862, vol. ii., p. 376. Drill attached to piston of a cylinder closed at one end. Drill raised by a cam attached to shafting moved by an engine. By raising drill, air behind the piston in cylinder compressed.	Stapff, "Ueber Gesteinbohr," pp. 48 and 49.
France, Feb. 27, 1863.	**DE LA HAYE.**—The drill is attached to a carriage consisting of two cross-shaped frames *f*, running on rollers on a guiding rod, the ends of which rest in two adjustable posts. The wagon and drill attached are run forward and backward by hand. An automatic contrivance for the rotating motion is attached. Weight of wagon and drill, 35 kilo.	Stapff, "Ueber Gesteinb.," pp. 49, 50, and 51. Cuts, Plate I., Figs. 8 to 16. Stapff's

TABLE 25. (*Continued.*)

DATE AND NUMBER OF PATENT.	NAME OF INVENTOR AND BRIEF OF DRILL.	PUBLISHED DESCRIPTIONS.
		authority: "Bulletin de la Société de l'Industrie minerale," Tome viii., livre 4, 1863; "Revue Universelle," 1865, pp. 282 and 563; "Berg u. Hütt. Zeitung," 1864, No. 3.
Sweden, Mar. 31, 1863.	**CHR. G. BARTHELSON.**—Hammer machine. Hammer is driven against drill by pressure of spring. Result: Hammer weighing 9 lbs. made a hole 2 feet deep in 48 hours! while a miner can make 4 to 5 feet in ten hours, same rock.	Stapff, "Ueber Gesteinb.," p. 48. Cut on Pl. I., Figs. 22 and 23. Stapff's authority: "Post och Inrikes Tidningar," No. 89 (A), 1863.
1863.	**SACHS.**—(Fig. 116.)* After having experimented for some time with	Stapff, "Ueber

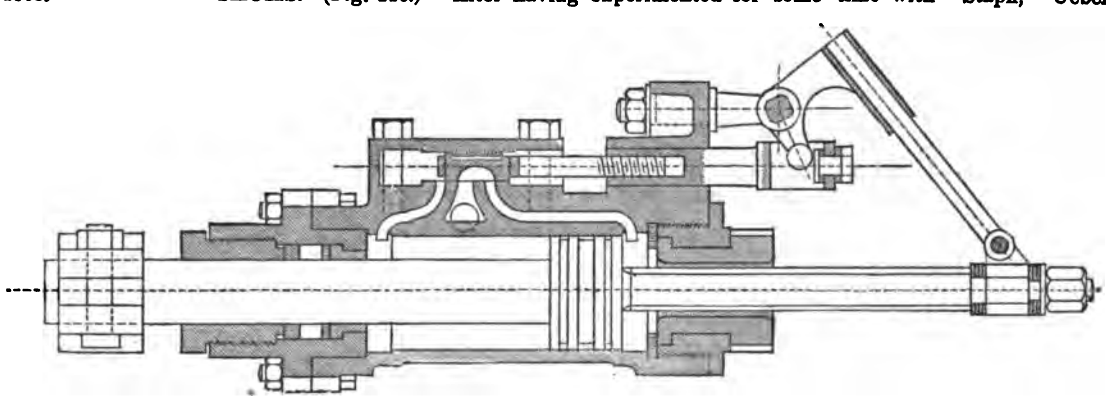


FIG. 116.

THE SACHS DRILL.

DATE AND NUMBER OF PATENT.	NAME OF INVENTOR AND BRIEF OF DRILL.	PUBLISHED DESCRIPTIONS.
	Schumann's machine at Altenberg Moresnet, with frequent alterations, Sachs constructed the following machine: *Valve motion.*—Advancing piston of working cylinder carries with it a bar, attached to the back part of piston by a joint. A lever moves the sliding valve. *Rotating motion.*—Same lever has an attachment which raises and presses down a bar, to which are attached two pawls moving ratchets. By them the rotating motion is effected. The *advance* is effected with the aid of a screw. Sachs' machine is by some called the *Tigler*, the name of the machinist who built them first.	Gesteinbohr," pp. 180 and 181. (See also cuts in Stapff, Pl. IX., Figs. 1 to 9; Pl. VII., Figs. 10 to 24.) Ržiha, "Eisenbahn-Unter- und Oberbau," p. 366. (See also cuts in Ržiha, Figs. 22, 23, and 24.)
1864.	**HIPP.**—A modification of Schwarzkopff's drill. Drill attached to piston of working cylinder. Used at Bingen-on-the-Rhine.	Stapff, "Ueber Gesteinb.," p. 61. Erbkam's "Zeitschrift für Bauwesen," 1867; "Polytechnisches Centralblatt," 1867; "Berg. u. Hüttenmänn. Zeitung," 1867; Dingler's "Polyt. Journal," 1867.

* The author is indebted for cut 116 to the "Humboldt" Company of Kalk, near Deutz on the Rhine. This Company subsequently manufactured the improved Sachs drill.

TABLE 25. (*Continued.*)

DATE AND NUMBER OF PATENT.	NAME OF INVENTOR AND BRIEF OF DRILL.	PUBLISHED DESCRIPTIONS.
Sweden, Dec. 4, 1865.	**BERGSTRÖM.**—Bergström's machine is an improvement on Schumann's. After a succession of trials with other constructions, Mr. Bergström built the one patented in 1865. *Valve motion.*—Besides the working cylinder, there is an auxiliary cylinder, which does double work. It has two pistons, which, in striking the sliding valve with nuts attached to their common rod at some distance from the pistons, cause the valve to move forward and backward. This valve distributes the air for both cylinders. The piston-rod of the auxiliary cylinder bears a cross-piece, which, with the aid of the rods, turns the fly-wheel. The fly-wheel shaft is fitted with a screw, which acting upon a cog affords the *rotary motion.* Hand-feed; weight 130 lbs.	Stapff, "Ueber Gesteinbohr.," pp. 163 to 180. Also, "Post och Inrikes Tidningar," No. 4, 1866; "Engineer," September, 1867, p. 261. "Engineering," Sept. 20, 1867, p. 261.
1865.	**FONTENAY.**—Long working cylinder, admitting of great variation in stroke. Extra cushioned blow. Sliding valve moved one way by compressed air, pushed back by three-cornered eccentric. Rotary motion by ratchet and pawl.	Stapff, "Ueber Gesteinbohr.," p. 118. Cuts in Stapff, Pl. I., pp. 39 to 42. See also "Practical Mechanics' Journal," 1865, p. 101.
Invented 1865. No patent issued.	**STAPFF.**—Working piston hollow, serves only to move slide-valve. In the hollow piston there is a second piston with the drill attached. Thereby automatic advance is gained for six inches. Second piston-rod is also hollow, and grasps at back a twisted square bar, fixed immovably thus giving rotation.	Stapff, "Ueber Gest.," p. 177. A cut is given in Stapff, Plate VI., Figs. 4 to 7.
1867.	**DE LA ROCHE TOLAY.**—Rotary drill. Diamond bit. Bit pressed against rock by piston in spiral cylinder. Rotary motion effected by Perret's hydraulic pressure engine. Piston-rod is six-cornered, and is hollow; water passes through it to wash away dust in the bore-hole.	Zwick, "Neuere Tunnelbauten," p. 65. Cuts 21 to 25. Stapff, "Ueber Gesteinb.," p. 230. Cuts, Plate X., Figs. 9 to 11. Pamphlet on "Perforateur à rotation et à pression directe de M. De la Roche Tolay, avec application du moteur à pression d'eau de M. F. Perret. Bordeaux, Mars, 1867." Also a recent very clear and well illustrated description of this drill has been published in De Bauve's "Manuel de l'Ingénieur," Part XII., p. 2.
1873.	**AZZOLINA DEL ACQUA.**—The valve is a cock-valve, like the one first used on the Burleigh American drill. The feed and rotation are on the same general principle as the Brooks, Gates, and Burleigh drill (American patent, No. 52,960), the drill being attached to a central screw and rotation, and feed performed by rotating the screw.	Rziha, "Eisenbahn- Unter- und Oberbau," p. 375. Cuts 34 to 37.
1875.	**TURRETINI.**—Valve motion effected directly by piston movement, similar to "Darlington;" rotation of drill effected by pressure of air; the advancing mechanism is based upon the principle of the *reaction of the compressed air,* which renders the advance exactly proportionate to the growing depth of hole; the arrangement is entirely without any delicate parts of construction, leading so frequently to repairs. (See Wood & Robinson's drill, American patent, No. 71,829.)	Rziha, "Eisenbahn- Unter- und Oberbau," p. 385. Colladon, "Die Maschinen Arbeiten St. Gothard Tunnel." Max Kraft, "Oesterreichische Zeitschrift für Berg und Hüttenwesen," 1874.

TABLE 25. (*Continued.*)

Date and Number of Patent.	Name of Inventor and Brief of Drill.	Published Descriptions.
1877.	**ADOLF MEZGER.**—Used in Rothschönberg Tunnel. Differential valve-piston (balance-piston) operated by the working piston. Adjustable expansion (by means of screw in head of the valve-cylinder). Rotation by friction apparatus, without cogs or other gearing.	
	R. SCHRAM.—See published descriptions.	Quite a recent machine. Description with cuts in the "Teknisk Tidskrift," Stockholm, March, 1877. Also see "Die moderne Spreng teknik mit ihren wesentlichen Hilfsmitteln Bohr- und Schräm- Maschinenen," etc., by Julius Mahler (Vienna, 1876), p. 9.
	CHAMPONNOIS.—Rotary ratchet-drill.	Stapff, "Ueber Gesteinb.," p. 236. Cuts in Stapff, Plate XI., 29 and 30. Also see Dingler's "Polyt. Journal," 1856, vol. cxlii., p. 90; "Annales des Mines," vol. viii., p. 97.
	LISBET.—Rotary drill. Machine attached to an iron pillar constructed of two parts, which may be lengthened and shortened at pleasure. Lower half of pillar notched to receive axle of drill. Advance automatic. Drill rotated with aid of gearing when hardness of rock requires it.	Stapff, "Ueber Gesteinb.," p. 238. Cuts in Stapff, Plate XI., 1 to 17. Also see Devillez, "Des Travaux de Percement," p. 228. Also "Bulletin de la Société de l'Industrie minerale;" "Revue universelle," 6 année, 3 livr., p. 316. Also "Practical Mechanics' Journal," Dec., 1867, p. 266.
	LISBET & JACQUET.—Lisbet's machine simplified. Has been used in French and Belgian coal mines (Angin, Seraing); also in Silesian mines; rejected at Saarbrück. Rživha, in his "Eisenbahn- Unter- und Oberbau," p. 355, gives the results of trials made with a Lisbet drill improved upon by Hagans and Von Balzberg; his data being taken from the "Berg und Hüttenmännische Jahrbuch," 1873.	Stapff, "Ueber Gesteinb.," p. 242. Cuts in Stapff, plate XI., 16 and 17.
	RŽIHA.—Rotary drill similar to Lisbet drill.	Rživha, "Tunnelbaukunst," p. 165. Cuts in Rživha, Fig. 94.
	ABEGG & RICHARDS.—Rotary drill. Simple ratchet-drill.	Stapff, "Ueber Gesteinb.," p. 244. Cuts in Stapff, Plate XI., 26 and 31 to 34.
	VILLEPIGUE.—Perforator. Rotary drill—worked by hand.	"Engineering," vol. x., p. 268. Oct. 7, 1870. (With cuts.)

CHAPTER VI.

THE APPLICATION OF MACHINE ROCK-DRILLS AND HIGH EXPLOSIVES IN MODERN TUNNELING —EXAMPLES OF SIX LEADING TUNNELS: NESQUEHONING, MUSCONETCONG, HOOSAC, SUTRO, MT. CENIS, AND ST. GOTHARD.

AT the close of Chapter IV. will be found some notes on heading and tunnel-driving through rock, by hand labor, and with black powder as an explosive. We will now consider the application of machine-drilling in the Nesquehoning, Musconetcong, Hoosac, Sutro, Mt. Cenis, and St. Gothard tunnels. For the details of the rock-drills and compressors mentioned, see Chapter V. Of the above tunnels, the Nesquehoning was driven wholly with black powder; in the Musconetcong Tunnel, dynamite was used; Hoosac was started with black powder, some dynamite was tried, but pure nitro-glycerine and Mowbray's mica powder were preferred; Mt. Cenis was started with black powder, and subsequently dynamite was used. At Sutro dynamite, and at St. Gothard dynamite and gum dynamite were used (see p. 91).

With regard to the use of machinery for drilling rock, no certain established rules can as yet be laid down as to when and where its best application will be found; nor would it be even safe in this chapter to give the results obtained in the above tunnels, typical as they may be considered, without at the same time presenting in full the histories of the tunnels themselves, and a view of all the circumstances under which the application of rock-drills was made. Thereby taking all the advantages and disadvantages of time, position, opportunity, etc., into account, some general idea may perhaps be formed of the relative part played by machinery as compared with hand labor.

PART I.

THE NESQUEHONING TUNNEL.

was the second railroad-tunnel in the United States in which machine rock-drills were adopted. (We shall hereafter see that machine-drilling was first practically applied on a large scale in America at the Hoosac Tunnel.) Nesquehoning was not given out on contract, but was built directly under the superintendence of Mr. J. Dutton Steele, chief engineer. The author is indebted to Mr. Steele for the following account of the construction of the tunnel:*

Nesquehoning Tunnel, in Carbon County, Pa., is a work of the Lehigh Coal and Naviga-

* A preliminary paper on Nesquehoning Tunnel, prepared during its construction, was read by Mr. Steele before the American Society of Civil Engineers, June 21st, 1871. (See Transactions American Society of Civil Engineers, No. 29, June, 1871. This paper was republished in Van Nostrand's "Eclectic Magazine," vol. v., p. 650.)

tion Company. It pierces Locust Mountain, and connects the railroad in Nesquehoning Valley with the extensive coal operations of the company in the valley of Panther Creek. Formerly this coal found its way to market by that interesting system of inclined planes and gravity roads known as the "Switch-backs of Mauch Chunk," which commanded the admiration of travelers for more than forty years, not only on account of the beautiful scenery which its route displayed, but also from its early and admirable adaptation to the purpose for which it was designed. It, however, became worked up to its capacity, and in arranging to extend their coal-mining operations, the company wisely determined to avail themselves of the locomotive, which had its practical development since they were the pioneers in railway enterprise. (See Chap. I., p. 25, for the early history of the Lehigh Coal and Navigation Company.) The tunnel passes through the base of the mountain at an elevation of some fifteen feet above the water on either side, and five hundred and forty feet below the crest, and cuts the strata at right angles, where they have a south dip of forty-five degrees. Its length is 3805 feet, of which 1305 feet are through the coal-measures, with all their various strata of coal, coal shale, sandstone, and conglomerate, 1200 feet through the conglomerate formation, with its occasional strata of coal slates and sandstone, 1000 feet through the red shale, with occasional strata of sandstone, and 300 feet, at the north end, through the *débris* and soft and decomposed red shale which is found overlying the red shale formation. It has encountered in its progress as hard and as soft material as is often met with in tunneling.

The geological section, Plate I., will show the strata encountered in detail, also the mode of operating, and the monthly progress in the several descriptions of work.

An old mining tunnel, which penetrated the coal-measures from the south end, was utilized as a ready-worked heading for a distance of 1200 feet, leaving 2600 feet of the pristine mountain to be penetrated; and an air-shaft, which had been worked out upon the dip of the mammoth vein at the extremity of the mining tunnel, was enlarged and used as a hoisting slope for a portion of the excavated material, and to facilitate ventilation. The work, therefore, consisted of enlarging the mining tunnel for a distance of 1200 feet, and of driving a new tunnel a distance of 2600 feet.

The section of the tunnel in solid rock is 16 feet wide and 19 feet high; but where arching is required, the full width for a double track is taken out, that a future enlargement may be made without disturbing the arches; and to secure a more thorough ventilation, the grade lines are so arranged that their extension from either end will pass out below the apex of the portals. They were also so arranged to produce sufficient drainage from either end during the progress of the work, but unlooked-for delays at the north portal (which will be hereafter referred to) made it expedient to do the major part of the tunneling from the south end, and caused the headings to meet midway between the summit and the north portal. The headings were driven at the bottom with the full width of 16 feet and a height of 8 feet, which gave the opportunity of either extending the heading from the south end, after passing the summit upon the southern grade, and thus maintaining a natural drainage, or descending on the northern grade and using pumps; the former was preferred, and hence the meeting of the headings at different levels, that will be observed upon Plate I.

After mature investigation, it was determined to use the Burleigh drills, driven by compressed air. With the advantage of the experience at Mont Cenis and Hoosac, as far as it was accessible and applicable, better results should have been obtained as to cost and progress than attended either of those works in their early stages. Mr. Steele is of the opinion that hand-drilling is incapable of penetrating the conglomerate formation met in that portion of the coal region with the economy and rapidity which is necessary to meet the present demands of capital. The whole work was done with six of the "two-drill" compressors made at Fitchburg, Mass., and with sixteen rock-drills. As much as one half of the rock-drills, on an average, were constantly in operation, and sometimes two thirds.

The explosive used was gunpowder, ignited by the electric spark; but the requirements of ventilation and the hardness of the rock demanded powder of the highest government standard. Some doubt which still existed among engineers at the time Nesquehoning Tunnel was started as to the economy in the use of the more powerful explosives, when the cost of drilling was reduced by machinery, and their supposed greater danger, with the then existing ignorance of workmen of their use, caused them to be rejected.* American steel was used, as several of our own makers produced a better and cheaper article for the purpose than could be obtained from abroad.

An iron pipe, six inches in diameter, conducted the compressed air from the compressors to the drills, a maximum distance of 3800 feet, with a loss of elastic power of about ten per cent. The average temperature of the tunnel was about 56° F., and the average air-pressure in working the drills about 45 lbs. per square inch, each drill being supplied by an elastic pipe of one inch in diameter. A slight congealing of the vapory particles of the atmosphere was observed about the exhausts of the drill-engines; but with the temperature and pressure above referred to, no inconvenience from that cause was experienced. The hoisting-engine at the head of the slope upon the mammoth vein was supplied with water by a small steam-pump, driven by compressed air from the general air-conduit, which was placed at the foot of the slope 1200 feet from the south portal. At this point, the temperature of the tunnel was considerably reduced by the currents of air up the slope, and, as a consequence, ice accumulated in the exhaust-valves, which made it necessary to check the currents by closing the foot of the slope.

The progress made with the heading will sufficiently indicate the general progress of the work, as the enlargement was carried on at several points simultaneously by passing out the *débris* under the carriages sustaining the enlargement-drills, and could be prosecuted as rapidly as was thought desirable. The heading-carriage at the south end (Mammoth Vein) commenced operating March 1st, 1870, and finished September 15th, 1871, a period of eighteen and a half months, in which it progressed 1950 feet, or at the average rate of $105\frac{4}{10}$ feet per month. Owing to the delays at the north approach already referred to, the heading-carriage at the north end (at the end of the soft-ground work) did not start until July 15th, 1871, and finished September 15th, 1871; it worked only two months and progressed 160 feet, or 80 feet per month in soft work; it was not fully equipped. The average monthly progress per single carriage was 104 feet.

The soft-ground heading and arching at the north end was commenced January 1st, 1871, and finished July 11th, 1871, a period of six and one third months, in which it progressed 335 feet, or 53 feet per month. The headings met on the 15th of September, 1871, 491 feet from the north end, instead of 1000 feet, as was originally expected, eighteen and one half months after they were started, and the excavation and masonry was completed in less than one year and ten months from its commencement.

The work consisted of excavation	44,852	cubic yards.
Dry masonry	726	" "
Stone masonry laid in cement	1,706	" "
Brick " " " "	1,709	" "

The cost of the work computed on the assumption of a loss of twenty-five per cent upon the plant, was as follows:

Excavation	$6 86	per cubic yard.
Brick and stone masonry in cement	10 29	" " "
Dry masonry	4 00	" " "

* The blasting throughout the construction of Nesquehoning Tunnel was remarkably free from accident, there being no loss of life from premature explosions.

The cost of the plant was:

For machinery	$51,387 65
" buildings	20,792 99
" mules and harness	4,700 00
Hoisting machinery, rails, trucks, air and water pipe, etc.	36,394 14
	$113,274 78

In further detail, we have the following:

Average length of holes drilled, per cubic yard of work	$5\frac{1}{3}$ feet.
Powder exploded	$3\frac{42}{100}$ lbs.
Drill steel expended	$\frac{25}{100}$ "
Oil and lights	11 cents.

In the heading we have:

In conglomerate, 11 feet of drilling and 6 lbs. of powder per cubic yard.
In red shale, $6\frac{1}{2}$ " " " " $3\frac{1}{2}$ " " " " " "

In the enlargement, the drilling was $3\frac{3}{10}$ feet, and powder $2\frac{7}{10}$ lbs. per cubic yard.

The total amount of powder used upon the whole work was 113,450 lbs., or $3\frac{42}{100}$ lbs. per cubic yard of rock removed, costing $54\frac{7}{10}$ cents per cubic yard. Total depth of holes drilled by machinery was 176,675 feet, or $5\frac{1}{3}$ feet per cubic yard of rock removed. Total amount of steel used was 8019 lbs., or $\frac{1}{4}$ lb. per cubic yard of rock removed, costing $4\frac{1}{4}$ cents per cubic yard. Total cost of lights was 11 cents per cubic yard of rock removed. These figures are for the whole work from start to finish, and cover both ends, arching, etc. As to the relative cost of hand and machine drilling, the following is an estimate based upon the experience at the Nesquehoning Tunnel:

Machine-drilling, including running and repairing, drilling and air-compressing machinery, and also steel and sharpening, cost, per foot of holes drilled	$14\frac{1}{10}$ cents.
Hand-drilling cost, exclusive of steel and sharpening, per foot of holes drilled,	50 "
There is included in the machine-drilling $3\frac{1}{10}$ cents per foot for steel and sharpening, which will be doubled in hand-drilling, making the cost of the latter per foot of holes	$56\frac{2}{10}$ "

There were $5\frac{1}{3}$ feet of holes necessary to remove one cubic yard, making the cost of drilling per cubic yard:

By machinery	$75\frac{2}{10}$ cents.
And by hand	$2 $96\frac{4}{10}$ "
In favor of machine-drilling	$2 $21\frac{2}{10}$ per cubic yard.

It is therefore safe to base an estimate upon a saving by machine-drilling of two dollars per cubic yard, *exclusive* of the cost of *plant* (according to the experience at Nesquehoning, and this estimate is an average upon the *whole work*, both heading and bottom included). Hand-drilling was used in the enlargement for one month, which increased both the length of holes and quantity of powder to the yard of rock, although it was in some of the softer portions of the work, showing that no better judgment is used in directing the drills by hand than is practicable by machinery, while the large saving in steel expended by the latter is a well-

established fact in the experience at Nesquehoning. The saving of light was inversely as the progress, and in explosives per pound in proportion to their force, in addition to the collateral saving of drilling, steel, and lights which will attend the use of the more powerful agents.

The cost of the work was considerably enhanced by the high prices which succeeded the civil war, and the disturbed condition of labor in the surrounding coal regions; the rates paid were two and a quarter dollars to drillers and two dollars to laborers, each, for eight hours' work. The drill-carriages and the Burleigh compressors used at Nesquehoning were subsequently purchased by Mr. Charles McFadden, the contractor for the Musconetcong Tunnel. They are shown in Figs. 72(b) and 101.)

The Nesquehoning Tunnel is exceptional in that in its construction machine-drills were used in driving a tunnel through the coal measures. As a general rule, hand labor is employed in similar formations. An account of a recent application of machine-drills in driving a mining-tunnel in the block coal regions of Northeastern Ohio, has been given in an article by Mr. C. D. Hersey, C.E., on the Brookfield Tunnel.*

The foregoing account of the use of rock-drills at the Nesquehoning Tunnel is of great and unique interest as being probably the only instance of a large tunnel in the United States in which we will ever have a record of power-drills with black powder, as, since its construction, the higher explosives have come into general use for heavy work. Indeed, at the time this tunnel was being driven, nitro-glycerine and mica powder were used at the Hoosac Tunnel, and giant powder or dynamite was coming into use at the West, but their application was not generally understood or as widely appreciated as at the present day.

We will now take up the Musconetcong Tunnel; for though it also, like Nesquehoning, was antedated in the inception of work by the Hoosac Tunnel, yet, owing to the great length of the latter, part of the more interesting portion of its rock-drilling work was done

* From Mr. Hersey's description we learn that in the work of removing the rock, drilling was done by hand in the inside part, and by power-drills run with compressed air in the outside part. Most of the portion driven by hand lay in sandstone. The manner of working as far as the coal reached, was to drive a heading in the coal. then blasting up the bottom rock in benches down to grade. After the tunnel went under the coal, the same process was continued, except that for the last forty yards the heading only was driven forward, in order to hole through, and thus the sooner finish pumping, as well as get better air. The part driven from the outer face lies wholly in shale, stratified horizontally, and having cracks or seams running through it (called "smooths" by the miners) every two or three feet in vertical distance. A heading, three to three and a half feet high, was started at the roof between two smooths, which were followed until they dipped a foot or so below grade, when the roof of the heading was broken through to another smooth, that was followed in a similar manner, and so on. Three to five holes, four to five feet deep, were bored in the face of the heading, charged with dualin, and fired at once, the central holes leading by a few seconds. This method of working cleaned out the rock completely from floor to roof of the heading. The enlargement followed from four to five yards behind, the bottom being blasted up or the roof down, as the case might be.

The crew engaged in removing rock at the outer face comprised, for twenty-four hours, 6 men in the heading, in shifts of 8 hours each, 4 men on the enlargement, in shifts of 10 hours each, and 2 men loading excavated rock into the mining-cars, working 12 hours each. There were outside at the compressor, 2 engineers and also 1 blacksmith. The average rate of progress per day was 6·7 feet, making, at the prices paid the men, the cost of *labor* only, for driving the tunnel full size, and putting the excavated material on to mining-cars, very closely approximate $4.25 per foot. The material through which some parts of the tunnel extend crumbled on exposure to the air, hence several hundred yards of it had to be timbered. In consequence of the work being done by the day instead of by contract, the data for estimating the exact expense is not at hand; but the entire cost of it as it stands completed ready for shipping coal, is not far from $35 per yard.

Twenty-one months was the total time employed in the execution of the work. ("Engineering News," Chicago, vol. iv., No. 16, p. 95, April 21, 1877.)

simultaneously with the Musconetcong Tunnel; and as the system of centre-cuts for blasting used in both tunnels was introduced into Musconetcong from Hoosac, a full description, from the author's personal experience of the system as used at Musconetcong, will suffice for both tunnels. It may be well here to note that the centre-cut system has also been adopted at the Sutro Tunnel.

PART II.

THE MUSCONETCONG TUNNEL.*

THE Musconetcong Tunnel is situated in New Jersey, near the line of the Central Railroad of New Jersey, about twelve miles from Easton, on the Easton and Amboy Railroad, the latter being the extension of the Lehigh Valley Railroad to tide-water.

The Easton and Amboy Railroad was constructed to afford the Lehigh Valley Railroad a direct through route to tide-water for its heavy coal traffic.

Preliminary lines having been run, the first location was decided on in the autumn of 1871 and winter of 1872, it being such, with regard to alignment and grades, as to insure the greatest economy in conducting transportation. Construction was commenced in the spring of 1872, and, from the first, the tunnel was especially pushed, from being the heaviest piece of work on the line. The road, on being ready for construction, was subdivided into four divisions. Mr. Robert H. Sayre, Chief-Engineer of the Lehigh Valley Railroad, being also Chief-Engineer of the Easton and Amboy extension; Mr. Calvin E. Brodhead, Principal Assistant. The tunnel was located in Division 1, Mr. John L. Wilson, Division Engineer, and Henry S. Drinker (the author), Resident Engineer. Mr. Charles McFadden, of Philadelphia, took the contract for the tunnel, and for several miles of construction adjoining each extremity.

Musconetcong Mountain is one of a range, around or through which a road from Easton to New York must go. Its summit is about 900 feet above tide-water, and 470 feet above the grade summit, which occurs in the middle of the tunnel, the one adverse grade to transportation occurring in the whole length of the road being between Phillipsburg and this point. The total length of the tunnel is a little less than a mile.

By consulting Plate II., the general formation of the mountain and the location of the different parts of the work may be observed. It will be seen from it that the preliminary top headings (shown by broken lines) passed through 770 feet of soft ground at the west end; 702 feet of this was subsequently arched, the balance being taken out in open cut. Next occurred 460 feet of limestone, and then 3731 feet of syenite, the latter continuing without change out to the eastern entrance. At the junction of the limestone and syenite, some 263 feet of arching was required, as the rock was found for some distance on either side of the line to be very loose and seamy.

This syenite may, in reality, be called a syenitic gneiss for the greater part of its length, as it seems to have a distinct stratification, the dip through both it and the limestone being invariably to the east, or against the mountain on the west side. In Plate II., it will be

* From a paper by the author of this work, on "The Musconetcong Tunnel," read before the American Institute of Mining Engineers, February, 1875; published in the Transactions of the Institute, vol. iii., p. 231. Also, in "The Engineering and Mining Journal," New York, May 29, 1875, vol. xix., p. 392; the "Railroad Gazette," New York, vol. vii., June 5 and 12, 1875; "Engineering," London, vol. xxii., pp. 120, 194, 351, 370, 416 (1876). Translated abstracts of the paper have also been published in several German periodicals, among them the "Organ für die Fortschritte des Eisenbahnwesens," 1877. II. Heft. Also the portion relating to rock-drilling and blasting is embodied in Alfred Lorenz's "Tunnelbau mit Bohrmaschinen-Betrieb," Vienna, 1877.

observed that the first rock met at the west end was a roll of limestone, occurring with an anticlinal axis in the open cut; this next gave way, for some hundred feet, first, to bands of decomposing, shaly limestone, and, possibly, some strata of Prime's "damourite," and then to seemingly stratified layers of red and white clay. Syenite was then encountered, with an anticlinal axis, evidently *in situ*, but partially decomposed, being most solid in the centre of the roll, where it required blasting. Then came another formation of clay, next occasional boulders, with much water; and then, with an adverse dip to the mountain, limestone again —the latter continuing, and meeting the syenite with this same adverse dip.

Before meeting the syenite, and near the junction, a large body of water was struck, and the limestone for some 50 feet was somewhat disintegrated, largely impregnated with iron pyrites, and the syenite, after the junction, continued soft and seamy for over 200 feet before becoming hard enough to support itself; arching was necessary through both the soft ground and under the loose rock. Between the syenite and limestone there occurred only a small vein of about six inches of soft, decomposed rock, with no intervening stratum of either slate or Potsdam sandstone. The syenite preserved mainly the same dip to the east, throughout its total length, except for some distance about the middle of the formation, where it seemed massive (shown in Plate 2 by crossed lines). Now, without hazarding any positive assertion on the subject, where so many plausible theories might be advanced, the supposititious formation, as shown in Plate 2, is offered to account for the position of the strata. It seems somewhat plausible, and if carried out, would make an anticlinal axis in the syenite somewhere in the east heading, probably. This would account for the parallelism of the dip on both sides of the mountain, and for the limestone underlying the syenite at the west end. At the east end no limestone was found, and no outcrop observed on the west slope, it being, probably, denuded, and only preserved in the supposed synclinal fold, as shown at the bottom of the slope.

The approach at the west end is through a cut about half a mile long, running from grade to about 75 feet of cutting at the entrance, mostly through earth, with some limestone rock, and a part through a soft whitish clay, resembling kaolin, which latter gave much trouble, the steam shovels, two of which were used, settling in it constantly.

This deep cutting at the west end, which we will treat of first, as it was by far the heaviest work, made it necessary to begin the tunnel by sinking either a shaft or slope to grade. A slope was decided on, and it was located so that its foot reached tunnel grade about 850 feet from the west end. This location was made that the solid rock might be soon reached and a heading started at once to the east. Then, while it was being driven, the open cut could be brought up, and any soft ground encountered between the slope and entrance arched.

Ground was broken for the slope in April, 1872; dimensions, 8 by 20 feet in the clear; length to grade of top heading, 276 feet, on an angle of 30°. It ran 190 feet through earth, necessitating timbering; collars of 12-inch oak, 4 feet apart from centre to centre, supported by end and two middle props, lagged at the sides and above with chestnut forepoling. The remaining distance was through good limestone rock, dimensions 8 by 16, the average progress through both rock and earth being from 7 to 10 feet per week. On reaching grade of tunnel-roof, on November 13th, 1872, top headings were started east and west, 8 feet high by 26 wide, by hand labor; progress, after getting fairly started, being in No. 1, or the heading driving east, in December 40, in January 57 feet. The work went on favorably in this heading during the winter. Machine drilling was introduced in February, raising the progress at once in Feb ruary to 69 feet, and in March to 95 feet, a rate subsequently very much increased after getting the machines in full working order, as will be shown. In April, when the face had advanced about 275 feet from the foot of the slope, the rock began to show signs of disintegration; the amount of water coming in increased, and the roof became so heavy that it was

found necessary to timber it with collars of 15-inch oak, set about 5 feet apart from centre to centre, lagged above, and sometimes at the sides, and supported either on legs or by hitches in the rock. These collars (1) were put in high enough to clear a 2-foot ring of masonry, and above them packing was securely blocked in, up to the roof.

On May 7th, 1873, about 3 P.M., a head of water was struck, first by a 2½-inch drill-hole, about 4 feet above the floor of the heading. The water forced the drill back and shot some fifty or more feet out into the heading in a steady stream, seeming to come from some large, pent-up reservoir. At 5 P.M., it was rising so fast that it was found necessary to take out the drills and pumps, to save them. At this time there had been two steam-pumps at work; one No. 7 Niagara, and one No. 5 Knowles. The water caught the last before it could be removed and hoisted. The Niagara pump was moved up the slope during the night, but it could not keep back the water, which continued steadily rising; it was taken out, and another similar one sent for, so that the two could be set to work on the water reaching its level.

The water still rose through the next day, but on the 9th it reached its maximum elevation within 120 feet of the top of the slope, or 70 feet beyond the junction of the limestone rock and earth, so giving cause to fear that should the water not be soon removed it might undermine the props of the slope timbering, and start the earth to working above the collars and at the sides, it being very treacherous material when moistened. On the 10th, the new pump arrived, and the two set to work, throwing, it was estimated, about 1500 gallons a minute. On the 14th, the water was lowered 20, and by the 15th, 40 feet, by incessant work, gaining back a few feet every time the pumps were moved down, and the latter had to be run at such a rate that they were soon badly racked. However, the pumping was being vigorously pushed, when suddenly, about 1 A.M. on the 14th, the water being at that time nearly 50 feet down, several sets of timber at water-level, and others below, gave way, the breakage subsequently continuing up to the surface of the ground, some hundred or more feet above.

This breakage, it will be noted (Plate 2), occurred at, and just above, the junction of the rock and earth, and seemed to be caused by the water having eaten away the backing of the side-props sufficiently to allow them a chance to sag outward, so throwing increased pressure on the roof. This disaster would practically necessitate a new driving and complete re-timbering, in all probability, of all the slope through earth below the level the water first rose to, as it was all in a dangerous condition, and this in the face of a head of water so strong that it would probably be impracticable to keep it back with such pumps as there would be room for while carrying on so difficult and delicate a task as re-timbering ground so heavy as this after having started "running."

It was thereon decided to sink a shaft. This shaft was located about 420 feet west of the bottom of the slope, the object being to push headings east and west from the shaft to tap and carry off the water from the slope workings to the open cut. On the 16th, the shaft was commenced at 1 P.M. It was so located as to clear 4 feet on the left and 12 feet on the right of the centre line of the tunnel (looking east). It measured 8 by 16 feet in the clear, timbered with 12-inch square white pine sets, placed at first touching, and lower, about 2 feet 6 inches apart in the clear; some of these latter sets were subsequently strengthened with liners. It was also strengthened from top to bottom by 12-inch pine braces, and by them divided into a 7-foot compartment on the left, for pumps and pipes, and an 8-foot one on the right for a hoistway. The shaft reached grade of the top heading, 110 feet down in five weeks, on June 21st, 1873, having been driven and timbered at the rate of 25 feet per week.

We may note that while the heading was being pushed east from the bottom of the slope, the one coming west was also driven on, but not so rapidly, so that when the slope workings were flooded, the heading coming west was advanced about 125 feet, its face being still in limestone rock, with 290 feet yet between it and the shaft. It was driven 26 feet wide by 7

feet high. To meet this, heading No. 3 was at once started east from the bottom of the shaft through earth, its dimensions in the clear being: top width, 8 feet; bottom width, 10 feet by 8 feet high. This was timbered in the ordinary manner used in mines with oak collars and props of 12- to 15-inch round timber; sets placed from 2½ to 3 feet apart from centre to centre, footed, in very soft ground, on 6-inch sills, but ordinarily on 3-inch foot-blocks. A similar heading (No. 4) was at the same time started west toward the open cut, the top bench of which was sufficiently advanced by the 30th of August to allow a shaft 32 feet in depth to be sunk at a point about 20 feet west of the proposed mouth of the tunnel. This reached bottom September 13th, 1873, and a fifth heading (No. 5), similar to Nos. 3 and 4, was started from this shaft east to meet No. 4, and driven at an average rate of 33 feet per week through earth.

To return to No. 3, or the heading driven east from the main shaft, to tap the slope workings. During July, it was driven and timbered through earth at an average rate of 20 feet per week, this rate being raised in August to 30 feet per week; at the same time the adjoining heading, No. 4, was driven at first at an average rate of 25 feet per week, and in September of 28, 36, 39, and, at the highest, 41 feet per week; the force required being generally 2 miners, 2 helpers, 2 laborers, and a boss or foreman.

When No. 3 had reached a point 165 feet from the shaft, still in earth, on August 13th, 1874, a large body of water was tapped in the face, there being at that point about 124 feet remaining between headings 2 and 3. The water was struck about 8 P.M., and rushed in with great force; it was estimated at not less than 3000 gallons per minute, or four times the capacity of the pump. This flow rapidly enlarged the original aperture, the material being soft. The men working in heading No. 4 had barely time to escape, as the shaft was quickly filled with water some 40 feet up, and the pump submerged.

Two No. 7 Niagara pumps were at once placed on the cage, lowered to water level and started; while gaining on the water, they did not lower that standing in the slope, leading to the unpleasant inference that this was a new reservoir, and that shortly all Jersey might be in with a determined effort to prove herself most indubitably interested, at last, in the cold-water movement. By the 19th of August, the water was pumped out, and it was found that, far from being exhausted, it had, in fact, dammed itself, the heading being completely blocked with sand half the distance from the face to the shaft. This was nearly cleared by the 21st, when, at 9 A.M., the water again broke in, this time bringing more sand with it, stopping the flow quicker, so that the water only rose some 25 feet in the shaft.

It was again pumped out by the 22d, at 10 A.M. After a delay of about a week, the heading was cleared, and an attempt made to drive it, by keeping a strong oak plank dam ahead. This was put in about 20 feet back of the old face, the planking being caught at the ends by the heading-props. A crevice below the bottom plank allowed the water to run out, and the top plank being removed, enough material was dug out to allow this plank to be put forward and braced against the next set of props. Then the second plank would be advanced likewise, and so down to the bottom; by this method a continuous dam was constantly kept up. With this the work was pushed through the 20 feet of sand up to the old face again, which was reached on September 8th, when an attempt being made to drive on the heading, the water again broke in, at 4 P.M., with such irresistible force that, in spite of every effort, it broke through the dam, and again drove out the men, filling the headings and part of the shaft. By 1 P.M. on the 9th, it was pumped out, and the men started to clearing up.

Meantime, the headings 4 and 5, designed to connect the shafts, had been pushed as rapidly as possible, work on No. 4 being resumed whenever the water was out of the shaft, and on October 7th, connection was made, so that, in case of flooding, the water could be pumped from both shafts at once. Work was resumed in No. 3, with a dam ahead as

before. On reaching the water, it again proved too strong, and drove the men out on the 13th, at 6 P.M. It was pumped out through the two shafts by 1 A.M., on the 14th. It was now decided by the Chief Engineer not to resume work on the main heading at once, but to leave the sand in the face as a dam, and to try to tap the water by starting a cross-cut

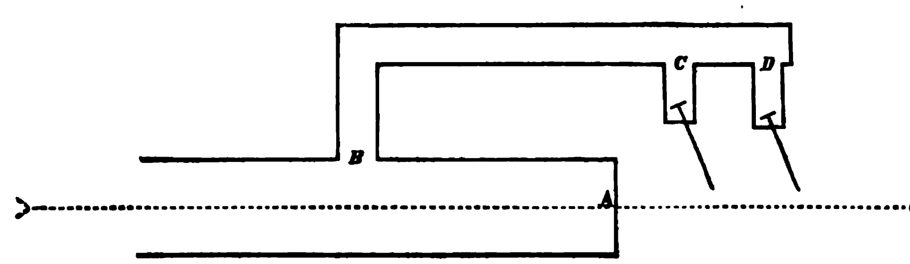


Fig. 117.
Scale, 20' = 1".

(Fig. 117), 4 feet wide by 6 feet high, at a point (B) about 25 feet back of the face (A). This was driven at right angles to the line of the tunnel, north 14 feet, thence ahead, parallel to the main heading, to a point (C) a few feet in advance of the face, thence south again about 6 feet. This was done without meeting water, so, on October 23d, at 1 A.M., an attempt was made to tap the water by boring ahead through the earth with a 3-inch auger, but unsuccessfully, so it was decided to drive on the parallel heading, and also to make another attempt to either drive on or get a steady flow of water in the main heading; the trouble being always that there was no chance to exhaust the body, as it invariably dammed itself, after doing all the damage possible. On getting up to the face of the main heading, the water came in again at the bottom, on November 4th, at 10 P.M., but this time was mastered by the miners quickly throwing across three dams in succession in which the sand lodged, so that it only rose some 2 feet above the bottom, without attaining a steady flow. The parallel heading, meantime, had been pushed on to a point (D) about 17 feet in advance of the face of the main heading, making its total length 42 feet, and another cross-cut was driven south, about 9 feet, toward the line of the tunnel. In it, by boring, the water was tapped on November 8th, at 9 P.M., it seeming to lie between a lot of loose boulders in sandy soil. The pumps were run to the limit of their capacity, at first keeping the water under control; but at the end of three days, being racked by incessant work, they gave out, and it rose to the top of the heading. By this time, the steam shovel had advanced the second bench of the open cut to within 55 feet of the second shaft, from which a heading, No. 6, had been driven 32 feet west, in October, in readiness to meet the shovel. A heading was now started, November 17th, in from the open cut, clearing the remaining 23 feet by November 20th, so giving, at last, a free vent to the water, which thereon spent its force in about 40 minutes, running the headings full, and spouting out in a huge jet, then subsiding into a clear running stream, carried by a ditch in the centre of the heading. Driving on the main heading (No. 3) was resumed, and it advanced in the next three weeks, still in earth, at an average rate, at first, of 30 feet per week; then, meeting the limestone at a point about 240 feet from the shaft, progress was reduced to 20 feet per week.

Meantime, the water standing in the slope remained stationary at its first level. By the first of October, however, it had gradually lowered to some 170 feet from the top, or the point to which the pumps had reduced it when the timbers broke, so that now it was found possible to keep the water down before the miners, the heavy head being off. The miners were therefore started to clean out and repair the damaged portions, and as soon as the water, on November 20th, found a permanent outlet through the shaft headings, it at once sunk in the slope to the level of the top of the heading, or roof of the tunnel. Now the height

of the tunnel through rock is 18.4 feet above base of rail. When arched, it is 21 feet in the clear above base of rail. Adding to this a 23·5 foot ring gives 23.5 feet to crown of arch; but the bottom of the collars, in a preliminary top heading through soft ground (where the English drawing-bar system is used), must clear at least 3.5 feet above the crown of the arch, to allow room for working the subsequent drawing-bars in enlarging, as will be explained hereafter. This makes the bottom of the collars in the soft-ground heading 27·0 feet above base of rail, or 8·6 feet above the roof of the tunnel through rock. As the soft-ground heading was driven about 8 feet high in the clear, its floor barely came on a level with the average top of the rock heading from the slope, as shown in Plate 2, so that the advantage gained and desired by tapping the water in the shaft was simply to take its head off, the steady stream that subsequently ran in the slope workings being pumped out at the slope, by, at first, one and, as the heading advanced, two No. 7 Niagara pumps.

Work was resumed in headings Nos. 1 and 2 about January 1st, 1874, and on the 3d, headings 2 and 3 met, thus affording connection between the shaft and slope workings, and leaving only the west heading, No. 1, from the bottom of the slope east, and the east heading, which had been from the first driving steadily west, with about 2335 feet yet to drive between them. As No. 1 advanced, the water was found to have been tapped by the drill-hole that first struck it, in a run-way in the limestone, about two feet wide, cutting across the line of the tunnel. The rock was found to continue so bad that it was decided unsafe to put in the drilling-machines, the constant jar being too heavy in loose rock.

The dividing line between the limestone and syenite was soon reached. Water was also constantly met in new springs as the headings advanced, so that the contractor for a long time was obliged to keep his pumps going steadily; indeed, until the open cut was brought up to grade, and the bottom heading, that was subsequently driven, connected with the rock enlargement.

After passing the dividing line of the limestone and syenite, the rock continued loose for some two hundred feet, requiring timber all the way as noted above (p. 305), when the loose limestone was first met in this west heading. Through all this loose rock the packing ran regularly from 4 to 5 feet above the collars, and occasionally as high as from 6 to 8 and even 10 feet, the collars being always put in so as to just clear a 2-foot ring of masonry. This, of course, gave an immense amount of loose rock to remove, and retarded the progress of the work, so that the advance gained did not exceed an average of 40 feet per month until the middle of May, 1874, or about one year from the time the water first broke into the heading. Solid rock being reached, the drilling-machines were put in, and the work at last might be called fairly started, with about 1725 feet of hard syenite still between headings—one of the hardest rocks, except trap, that has been encountered in tunneling in our Eastern States; harder and tougher, it is said by judges familiar with both, than any body of rock encountered in the Hoosac Tunnel.

At the west end, four Burleigh compressors were used to run the drills. These compressors were the ones known ordinarily as the "two-drill compressor," consisting of two vertical air-cylinders run by a horizontal steam-engine (see Chapter V. for description in full). Four of these compressors were found sufficient to run the nine drills usually kept going in the heading and bench. To furnish steam for them, four return tubular boilers of 45 horse-power each were used. The compressed air was conducted by a 6-inch pipe, at first about 1300 feet, and, before the headings met, about 3000 feet, before reaching the drills, and it was observed that the loss of pressure rarely exceeded from 2 to 3 lbs. (per square inch), and generally was still less.

The Ingersoll drill was adopted by Mr. McFadden, and used throughout the prosecution of the whole work, giving entire satisfaction. At first 3½-inch and then 4-inch drills were

tried, but, finally, the 5-inch was decided on as by far the best size in the hard rock encountered. This drill was found to run months with little or no repairing necessary, and such repairs as were needed were generally more in consequence of wear than breakage, the parts giving out first being usually the feed-pawls and ratchets. (For full description, see Chapter V., p. 264.)

The drills were mounted in the heading on two carriages, one on each side of centre line. These carriages were simply stout frameworks of oak, running on tracks carried up to the face of the heading, each supporting in front three horizontal iron bars, on which the drills were so clamped as to insure convenient lateral and vertical motion. Fig. 118 shows a front

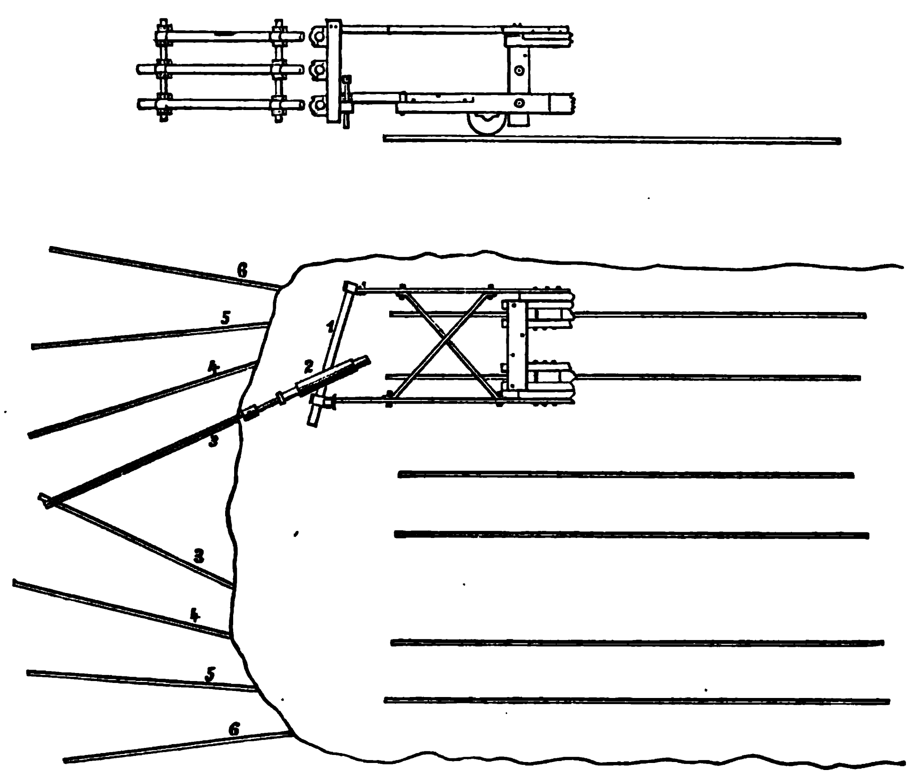


FIG. 118.

THE AMERICAN CENTRE CUT SYSTEM OF HEADING BLASTING.

Scale, 10′ = 1″.

and side view, and plan of the fore-part of one of these carriages, there being two in the heading, one on each side. (See also Fig. 101.) After a blast, all hands are at once engaged in shoveling and filling the broken rock into the middle of the tunnel between the machine-tracks, so as to clear the latter. As soon as the way is clear, the carriages are at once run up to the face, and drilling recommenced, and the broken rock subsequently removed by cars on a centre track. The heading being twenty-six feet wide, there was room enough to accommodate the three tracks, and by proper switching there was rarely any detention from want of cars. As to the manner of drilling holes, the west heading, after passing the loose rock, was all broken by the method of centre-cuts, and subsequent squaring up. This method was introduced at Musconetcong from the Hoosac Tunnel, where it was originated. Giant powder or dynamite was adopted as an explosive by Mr. McFadden.

The American Centre-cut System of Heading Blasting.

The method of blasting by cuts is based, of course, on the extraordinary force developed by a comparatively small bulk of explosive matter. It consists in first blasting out an entering wedge or core, about 10 feet deep at the centre, and subsequently squaring up the sides by several rounds. To do this, first 12 holes are drilled by the six machines, three on a side, the holes placed as shown in Fig. 119, and marked C; A being the floor of the heading. These 12 holes are drilled two and two, six on a side, with from $1\frac{1}{2}$ to $2\frac{3}{4}$-inch "bits," the two sets being started about 9 feet apart, and at such an angle as to meet or cross at the bottom, the largest bits being put in first. They are then charged with about 25 lbs. No. 1 and 50 lbs. No. 2 giant powder, and fired simultaneously by electricity. No. 1 is only used for cuts, inasmuch as in them a quick, strong powder, comprised in a small bulk at the bottom of the holes, where the greatest resistance will be found, is required, while the No. 2 added serves in filling the holes, so starting the sides of the cut as the apex moves. The cut being out, a second round of holes is started for the first squaring up, as shown by the numbers 1, 1, 1, 1. In these, and in the subsequent rounds, 2, 2, 2, 2, and 3, 3, 3, the resistance is pretty equally distributed along the whole length of the holes, and is also, of course, not so great as in the cut; therefore, No. 2 is used, as in it the nitro-glycerine being mixed with a larger proportion of absorbent matter, the force is thereby distributed over a greater space.

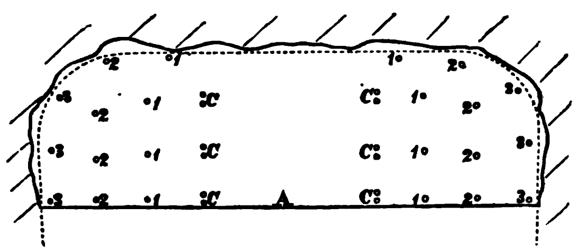


Fig. 119.

THE AMERICAN CENTRE-CUT SYSTEM OF HEADING BLASTING.

Scale, 10′ = 1″.

In the first and second squaring-up rounds, from 50 to 60 lbs. of No. 2 are charged, and in the third from 80 to 90, the holes getting stronger as the arch falls at the sides; there are generally also one or two additional roof-holes in the third round that are not shown in the figure, their position being variable, according to the lay of the rock. The top holes in the first round are also designed to bring down any roof not shaken by the cut, and are, therefore, given a strong angle toward the centre, and always drilled from 12 to 14 feet deep. The horizontal projection of the above holes is shown in Fig. 118, 3 being the cut holes, 4, 5, and 6 the squaring-up rounds. As to their relative depth, the holes of the first squaring round are always drilled a foot or more deeper than the cut holes, and when blasted they generally bring out a foot additional of shaken rock at the apex of the cut. The following table will approximately show the number and depth of holes required, and the powder used for a lineal advance of ten feet in heading work:

TABLE 26.

	No. of Holes.	Depth of Holes.	Total Depth of Holes.	Lb. No. 1.	Lb. No.
Cut	12	10′ 6″	126′	25	50
1st square up	8	12	96	..	55
2d " "	8	12	96	..	55
3d " "	6	12	72	..	85
Additional roof-holes	2	{ 10 8 }	18	.	..
	36		408	25	245

Now, allowing the cut holes to be 10½ feet deep, the cut will generally blast out about 9 full feet linear, which, as explained above, is raised to 10 in the subsequent rounds.

Assuming the average cross-section in an 8-foot heading to be about 175 feet for a lineal advance of 10 feet, 65 cubic yards of rock would be broken, which would give an average of, say, four tenths (0·4) lb. No. 1, and four (4) lbs. No. 2 giant powder burnt, and a little over six feet of holes drilled, per cubic yard broken.

This, however, it should be noted, would often be increased by occasional block or side holes, and is assumed for a case in which no holes are supposed to have missed, and in which no secondary drilling and blasting are required. Proportionate amounts would have to be added for such cases.

The above estimates are based on ordinary 10-foot cuts; there were, however, many instances of 12- and 13- and sometimes 14-foot cuts taken out by ambitious foremen; but even dynamite has its limit of strength, and working too deep cuts is not advisable, as they will often only blow out partially, leaving the rock in awkward shape. As to the division of time in heading work, to drill and square up a cut should take about four eight-hour shifts, with such rock as was met at Musconetcong, it being, as stated, unusually hard and tough. It will take one shift to drill and blast the cut and one shift to each of the three rounds, and this with a force of 12 machine men (one driller and one helper to each machine), 6 laborers for loading broken rock, 1 nipper for carrying tools, and a boss. On an average, however, this standard will hardly be reached, as it provides for no stoppage, no missed holes, and no accidents, and, unfortunately, tunnel-headings, like all things earthly, are liable to occasional stoppages and accidents. However, a standard approximating this can be attained, and was attained in the west heading at Musconetcong, in the latter part of the work.

Before taking up the east heading, we will consider in a few words the enlargement in rock of west heading No. 1. This "bench," as the rock enlargement is termed, was kept both on the east and west sides from four to six hundred feet back of the headings, so avoid-

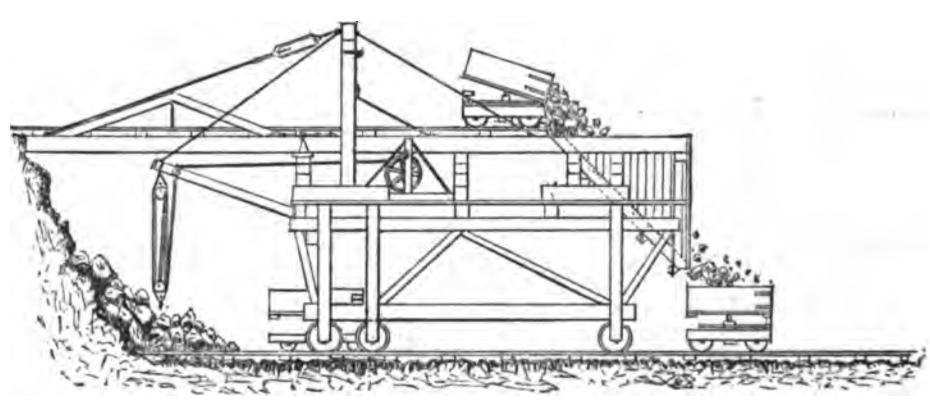


FIG. 120.

BENCH-CARRIAGES USED AT HOOSAC AND MUSCONETCONG TUNNELS.

Scale, 10′ = 1″.

ing any interruptions at the bench from heading blasts, and allowing plenty of room for handling and switching cars, also for backing the machines to a safe distance from the face when blasting, etc. In taking up the west bench, there was no extraordinary detention; the work was begun about January 1st, 1874. Its steady advance, however, did not commence until July, 1874. Up to that time, though the headings were of course free from water, the flow remained so great that frequently the enlargement, on the shortest stoppage of the pumps, would become flooded several feet in depth; also, until the headings met, in December, 1874, both

the west and east enlargements were detained by the time lost in removing the broken rock from the headings. This was run out from the top heading on a movable bridge extending over the men at the bench, and ending in a shute, into which the cars were dumped (Fig. 120). From this shute the rock was again loaded on cars in the bottom, and run out to the slope. Every time, therefore, that a blast was fired, this bridge had to be run back, and then up again to the face as soon as the track could be cleared, much time being often lost in the operation from unavoidable detentions that frequently arose. The different rates of progress

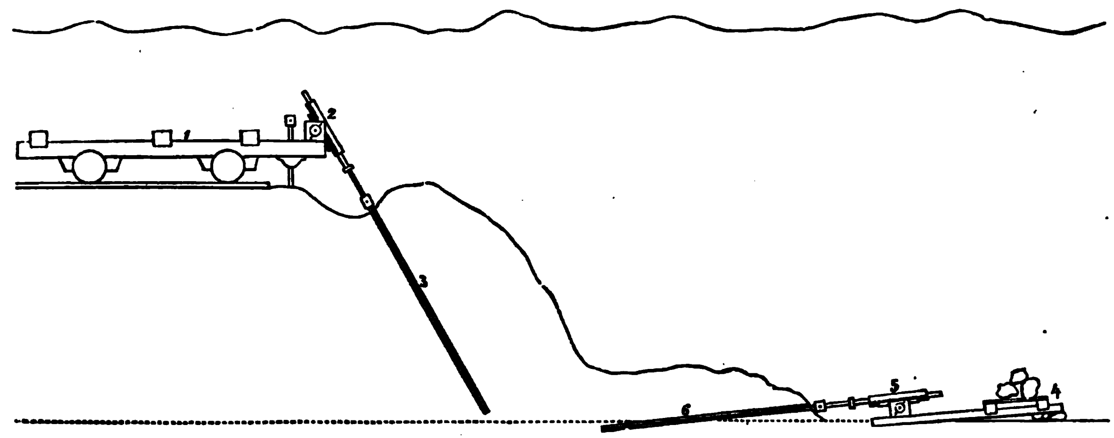


FIG. 121.
TAKING UP THE BOTTOM.
Scale, 10′ = 1″.

attained in running a bench with a heading in front, and after the headings are cleared, is shown in Tables, p. 372, by which it will be seen the average monthly advance was raised in the west enlargement from 87 feet, in 1874, to 188 feet, in 1875, on the meeting of the headings in December, 1874; the increase in the east enlargement being from 96 feet, in 1874, to 181 feet, in 1875. Figs. 121 and 122 show the method of blasting adopted in enlarging in rock. First, six top holes, from 12 to 13 feet deep, are drilled and blasted; their relative position is shown in Fig. 122, which is a horizontal projection of the heading, A being a centre line, B the sides in the enlargement, (B′) sides of heading, C face of bench, and 1, 2, 3, 4, 5, 6, the holes. These six lift most of the rock; what is left is broken by several horizontal holes shown by (6) in Fig. 121, in which 1, 2, and 3 are the top carriage, drill, and location of hole; and 4, 5, and 6 the bottom carriage, etc.

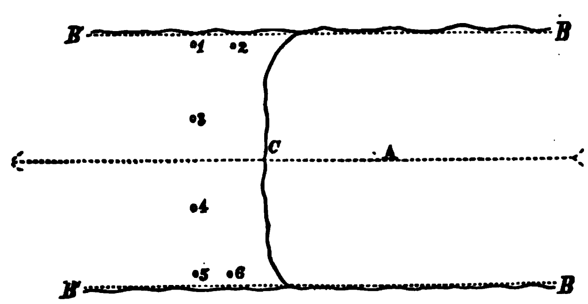


FIG. 122.
PLAN OF BENCH.
Scale, 20′ = 1″.

These two sets of holes, top and bottom, will average a linear advance for the bench of 9 feet, the following being a fair estimate of the number of feet drilled and powder burnt (for 9 feet of advance).

TABLE 27.

	No. of Holes.	Depth of Holes.	Total Depth of Holes.	Lb. No. 2 Dynamite.
Top holes	6	12 ft.	72 ft.	62 lbs.
Bottom holes	4	10 "	40 "	45 lbs.
Totals	10		112 ft.	107 lbs.

The total height of the cross-section adopted for the tunnel through rock, from lower sub-grade (1·75 feet below base of rail) to roof, was 20·15 feet; with an 8-foot heading off, this leaves about 12 feet of a bench, with an area of 306 square feet, which gives about 102 cubic yards to a lineal advance of 9 feet, or 1·05 pound No. 2 dynamite, and 1·1 foot of holes drilled to one cubic yard of rock broken, holes being drilled with from $1\frac{1}{4}$ to $2\frac{3}{4}$-inch bits, the largest bits being put in first. In general, three machines are kept in use at the bench, two on top and one below; to run them, 3 drillers and 3 helpers are needed, about 14 laborers to clear away rock, one nipper, and a boss.

Before speaking of the east end, it may be well to state that the enlargement in rock of No. 2, or the heading driven west from the slope, was not pushed during the foregoing work, there not being the same necessity for haste. After passing the junction of headings Nos. 2 and 3, it was driven on to a point about 175 feet from the slope. There the rock giving out, the enlargement in earth, to be followed by arching, commenced.

The East Heading

had no serious natural detention from its beginning to end. Its monthly progress is shown by p. 372. The open cut was sufficiently advanced by July 22d, 1872, for the top heading to be commenced. It was started in a very loose, decomposed syenite, and driven for the first 60 feet of the size of, and timbered in the same manner as, the small earth heading at the west end, this small heading being subsequently taken out in open cut. At that point, meeting solid rock, the heading was enlarged to the full width of 26 feet, and driven on by hand labor, until the machines were introduced in January, 1873. Giant powder and Ingersoll drills were used as at the west end, and centre-cut blasting was begun in November, 1873, making at once a marked difference in the rate of progress, as the men became more familiar with it, raising the progress from the previous average of 89 feet per month in 1873 to 116 feet in 1874. The compressors were of the Rand & Waring make (see Chapter V., p. 153), and were located about 300 feet from the mouth of the tunnel, giving the air about 2800 feet to travel at most, by the time the headings met. Four of them were in constant use, three of 12-inch and one 16-inch air-cylinder. These compressors consist of a horizontal air-cylinder, driven by an oscillating steam-cylinder.

Steam for running the compressors was supplied by five large locomotive boilers, of 50 horse-power each, and all the coal and machinery used at this end of the tunnel had to be carted some five miles over a heavy mountain-road, from the New Jersey Central depot on the west side.

To expedite the work, the contractor had in use the latest and most approved machinery, and no means were spared to push the work in every possible manner. The plant found necessary comprised: 26 Ingersoll drills, 4 Burleigh and 4 Rand & Waring compressors, 4 return tubular boilers at west end, 5 large locomotive boilers at east end, 2 machine-shops with repairing outfit, one at each end; about $1\frac{1}{2}$ miles 6-inch air- and water-pipe; 2 hoisting-engines, one each at the slope and shaft; 4 locomotive boilers to run them; a number of steam-pumps in constant use; 2 steam-shovels for removing the west end open cut, run constantly day and night, and 2 small locomotives to run out the open cut, and such of the tunnel material as could be brought out of the entrance.

All material for the west end for over two years had to be carted nearly a mile by rough roads from the Central Railroad; the coal-carting alone made a heavy item of expense, so that the east and west ends together kept some twenty-four four-horse teams in constant employment. About 1000 tons of soft coal were burnt in the course of the work, by the steam

shovels, blacksmiths' shops, and locomotives, and it took about 26,500 tons of anthracite, in the three years, to supply steam for the slope and shaft hoisting engines, pumps, and the west and east end compressors. In the whole amount of tunnel-work, about 14 tons No. 1 and 70 tons No. 2 dynamite were used; quite a large amount, including some black powder, being also consumed in blasting rock met in the open cuts. Some black powder, also, was used at first in the tunnel at the start, before the introduction of dynamite.

Now, as there were about 82,000 cubic yards of rock excavated in the tunnel with dynamite, this gives, as a total average, about 0·34 lb. No. 1 and 1·71 lb. No. 2 burnt per cubic yard of rock broken, inclusive of all work, which tallies, it will be found, pretty well with previous estimates made of the powder consumed in heading and bench work; as for heading work, it was estimated that about 0·4 lb. of No. 1 was burnt per cubic yard of rock broken, and this proportion is reduced in the general average, probably, by some No. 1 occasionally burnt at the bench. Again, in the heading work, it was estimated that some four lbs. No. 2 were burnt per cubic yard broken, and at the bench 1·05 lb. As the rock broken in the heading would run about one third of that in the bench, the total average of 1·71 lb. per yard for the whole tunnel is not far from a mean.

In exploding this powder, 5400 feet of leading wire and 805 lbs., or 261,625 feet, of connecting wire were used; also 55,100 exploders, with an aggregate length of 567,200 feet of wire attached—making in all a total length of 834,225 feet, or about 16½ miles of wire used. For blasting by fuse, some 200 boxes, or about 20,000 caps, were consumed.

When in full progress, Mr. McFadden had constantly a force of about 1000 men on hand, and with them built up a settlement of several hundred shanties on each side of the mountain.

With reference to these men, it may be noted that the experience at Musconetcong paralleled that on most public works in the obstacles encountered by every contractor—namely, the swarm of liquor-shanties, which, if not soon checked with a stern hand, will every month throw the work almost idle for a week following pay-day. New Jersey law, being proverbially infallible, might have been expected to be sufficient to stop peremptorily a large unlicensed sale of liquor; but though her laws may ordinarily do for the home-rule of the simple and peace-loving aborigines, it was found necessary, on the introduction of a more active community, to pass some special provisions for their benefit; among these laws was one rendering the sale of liquor, in quantities under five gallons at a time, within three miles of either extremity of the Musconetcong Tunnel, a crime punishable with a year's imprisonment, or one hundred dollars fine, or both, for each offense. Under this law, several convictions being at once secured, the nuisance was effectually abated for the time that the men were most needed.

Résumé.

And now, it may be interesting to note, in a few words, what the history of this tunnel in reality has been; how the three years of its construction have been spent; what plans were adopted by the Chief Engineer in designing the work, and what means were employed by the contractor for the execution of the same, so as to enable him, in comparatively so short a time, to overcome difficulties as persistent as they were formidable.

First, it will be noted, that, in laying out the work, the deep and long cutting at the west end necessitated the starting of the tunnel by a slope, and that subsequently, on heavy bodies of water being met, this cut, for a long time—in fact, through the majority of the work—prevented economic drainage being obtained by bottom headings through the soft ground, as, until the bottom bench of the open cut was out, of course the water had still to be raised by

pumping, while at the east end, the heading and enlargement started directly in from the open cut, and meeting solid rock almost at the start, progress went steadily on without any serious natural obstacle, to the completion of the work.

To revert to the west side again, it will be remembered that after getting the heading fairly started to the east from the bottom of the slope, water was met in May, 1873, in such quantities as first to flood the tunnel, and then, by causing the disaster to the slope, to entirely stop all work in the heading until January following. But, in addition to this sheer and direct loss of eight months, it must be remembered that after getting to work again in the heading, it was not until May, 1874, that the rock became firm enough to introduce machine-drilling, and that in the four months intervening between the resumption of work in the main heading, in January, 1874, and the meeting of this solid rock, in May following, owing to the time lost in timbering and taking down loose rock, a total advance of only about 160 feet was accomplished, a distance subsequently equaled in a single month by machine-drilling (November 14th to December 15th, 1874). Now, this brings us to May, 1874, to just one year from the time the heading was drowned out, making a dead total of one whole year in this heading, in which, in spite of every effort, an advance of only 160 feet was gained, from the natural and unforeseen difficulties encountered.

Now, when loose rock was first struck in this west heading, March, 1873, at a point about 275 feet from the slope, there were yet 3256 feet between headings. After the machines got fairly to work at the west end, they made an average in the six months beginning June 1st, 1874, of 135 feet per month, through a rock which was pronounced harder and tougher than any met with in the Hoosac Tunnel, by judges familiar with both. At this rate, the east heading would probably have been met June, 1874, the enlargements in rock would have been close after, and the tunnel completed nearly a year sooner; for the soft-ground arching, had it not also been detained by water, could have been probably pushed so as to keep up. Again, had this tunnel been driven throughout, as certainly many tunnels have been, in moderately firm rock, however hard, and without meeting such persistent natural obstacles according to the record shown of the progress now possible to attain through the agency of machine-drilling and high explosives, it might well have been finished at, say, the moderate rate of 125 feet per month of the headings, within less than two years from the start, as the main headings from the slope east, and from the east coming west, would have holed in about sixteen months, during which time the heading from the slope west and the enlargements would have been going on, and leaving *eight clear months* of the two years for delays in starting, pushing the open cuts, finishing enlargements, and for accidental stoppages, etc. etc.

PART III.

THE HOOSAC TUNNEL.

Geological Formation of Hoosac Mountain.* (See Plate 3.)

The rocks of the Hoosac Tunnel are in general as follows: Mica-schists, passing into micaceous gneiss, more or less feldspathic, having sometimes a seemingly conglomeritic

* For the section, Plate 3, showing the formation of Hoosac Mountain, and the accompanying notes thereon, the author is indebted to Mr. Charles E. Hall, Assistant Geological Survey of Pennsylvania. Dr. T. Sterry Hunt has further kindly suggested some notes regarding the same.

character, and granitic gneiss. The profile of the mountain from the central shaft to the east portal shows the varying firmness of the rock: strong quartzose mica-schists forming the east crest of the mountain, followed by softer and more readily disintegrating mica-schists, which form the depression between the two crests. The uppermost series, or that which extends from the east portal to about 8000 feet in the tunnel, has a vertical thickness of not less than 6500 feet. The rocks underlying this to the west have a more gradual dip to the eastward, extending a distance of 6500 feet through the tunnel east of the granitoid anticlinal. This series of mica-schists and gneisses has a vertical thickness of 3500 feet. It is repeated in the tunnel west of the anticlinal, and extends from the west shaft a distance of 3700 feet east. The rock in this portion of the tunnel is much contorted and broken. The granitoid gneiss extends a distance of 4500 feet through the tunnel, with a vertical thickness of not more than 500 feet. For the greater portion of the distance this rock lies nearly horizontal. The tunnel was arched from the west portal to the vicinity of the west shaft, previous to examination, and there was therefore no way of identifying the strata of that portion with those met with beyond. The dip of the rock in this portion has been indicated as received from the engineers. The rock through this section was generally much decomposed, and arching found to be necessary.

Dr. T. Sterry Hunt considers this decomposed mass to be the same rock as that of the mountain, and maintains that agencies (glacial) which have swept off the decomposed surface from the entire upper portion of the mountain have spared this protected western flank. That the whole surface of the mountain rock was, prior to the glacial period, decayed to a variable depth and swept off during that period, is a fact beyond a doubt.*

Total vertical thickness of rock exposed in the tunnel, 10,500 feet.

The relations of the so-called Stockbridge limestone, at the west portal, with the gneiss of the mountain, Mr. Hall is not prepared to explain without further examination. He feels convinced, however, that there is a break, and that they belong to two distinct series.

History of the Hoosac Tunnel.†

The project of tunneling the Hoosac Mountain was broached as early as 1825. In that year a board of commissioners, with Loammi Baldwin as engineer, was appointed to ascertain the practicability of making a canal from Boston to the Hudson, in the vicinity of the junc-

* See on this point also a paper by Dr. T. Sterry Hunt, in the "Proceedings of the Boston Society of Natural History," vol. xviii., pp. 106–108, June 2d, 1875.

† The following history of Hoosac Tunnel has been compiled by the author chiefly from the Massachusetts Legislative Reports, running from 1848 to 1877. A number of these reports, including the valuable one of February 28th, 1863, were presented to him by Dr. T. Sterry Hunt, of Boston. A number of others he was able to purchase; but for the great bulk of the reports he is indebted to Mr. C. D. Elliot, of Somerville, Mass., who kindly loaned his set, on hearing that this work was in preparation.

For the illustrations of work at Hoosac Tunnel, and of the rock-drills and compressors used (see Chap. V. for latter), the author is further indebted to the State Library of Massachusetts. The full State set of photographs there preserved were, on the application of Mr. Thomas Doane (formerly Chief and late Consulting Engineer of Hoosac Tunnel), to the Governor and Council of Massachusetts, kindly loaned to the author to copy or to make notes from. It has been impossible, on account of the expense, to reproduce but a limited number of them; some of these will be found in the following account and in Chapter V. on rock-drills; but the great advantage to the author in having the use of these photographs (and also a final profile of the tunnel, also preserved in the State Library), has been in their suggestive character, as making clear many involved points in the State Reports, and supplying many missing links in the latter.

The tables of progress have been compiled from the State Reports, but full details of all work done on the tunnel, of which any records are available, will be found in the profile Plate 4, for the preparation of which the

tion of the Erie Canal with that river. Their report (Massachusetts Commissioners' Report, 1826, p 141) declares that "there is no hesitation in deciding in favor of the Deerfield and Hoosac River route," and that "there is no hesitation therefore in deciding in favor of a tunnel; but even if its expense should exceed the other mode of passing the mountain, a tunnel is preferable."

Railways being shortly after introduced, the canal project was dropped. In 1828, surveys were made for three routes to afford Massachusetts railway connection with the West, viz., by Greenfield, by Northampton, and by Springfield. The last or Southern route was chosen. The work was not begun immediately, but Massachusetts never lost sight of the advantage of a direct route to the Hudson River. This was finally accomplished in 1842, by the completion of the Western Railroad to Albany. In 1848, an application was made for a charter for a railroad from the terminus of the Vermont and Massachusetts line, at or near Greenfield, through the valley of the Deerfield and Hoosac, to the State Line, there to unite with a railroad leading to Troy. The charter was granted, and the corporation organized June 1st, 1848, the capital stock being limited to $3,500,000.

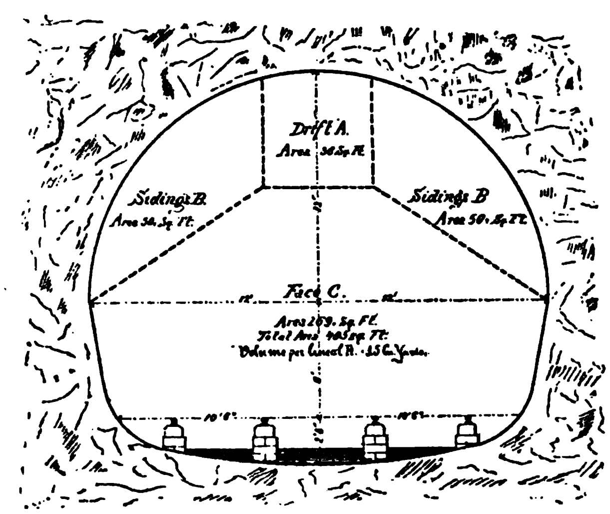


FIG. 123.

CROSS-SECTION OF HOOSAC TUNNEL.

Proposed by Mr. A. F. Edwards, Chief-Engineer in 1851. Scale, 10' = 1"

The location of the line was filed in the clerk's office of Franklin and Berkshire counties, in November, 1850. (In October, 1850, a contract was made with Gilman & Carpenter for the construction of the road.) In 1854, an act passed the Massachusetts Legislature "to enable the Troy and Greenfield Railroad Company to construct the Hoosac Tunnel," by which the State, on certain conditions, lent its credit to the amount of $2,000,000. The estimated cost of the proposed double-track tunnel was $1,948,557, and of the road and equipment, $1,401,443; total, $3,350,000. This estimate had been made by Mr. H. F. Edwards, the first engineer.

Fig. 123 shows the cross-section of the tunnel as proposed by him; his detailed preliminary estimate for the tunnel was as follows:*

"*A Brief Statement of the Highest Estimate and Longest Time for the Construction of the Tunnel Section of the Troy & Greenfield Railroad.*

"The length of the tunnel from heading to heading is 24,100 lineal feet, in volume equal to 15 cubic yards per lineal foot.

"Total amount of excavation.................. 361,500 cubic yards.
Cost of the tunnel per lineal foot............... $69 52/100 viz.:

author is indebted to Mr. Edward S. Philbrick, of Boston, State Consulting Engineer, during the Shanly contract, 1871–'75, and to Mr. Benjamin D. Frost, Superintending Engineer, during the same period; also a set of notes on the cost of machine rock-drilling, especially prepared for this work by Mr. Walter Shanly, C. E., of Shanly Brothers, contractors, will be found following the history of the tunnel.

For the many courtesies shown him by the above gentlemen, the author respectfully tenders his grateful acknowledgments.

* Report of Joint Committee on Railways and Canals, Massachusetts State Reports. (Senate, No. 57, p. 4, March, 1851.)

A (see Fig. 123),	36 feet,	at 50c.	per foot,	$13.50	per yard	....	$18 00
BB,	100 "	" 30c.	" "	8.10	" "	....	30 00
C,	269 "	" 8c.	" "	2.16	" "	....	21 52
	405 cubic feet, equal to 15 cubic yards					....	$69 52

Cost per cubic yard 4 63½

The whole amount for excavating tunnel	$1,675,432
Masonry, 6025 perches (25 cubic feet), at $5	30,125
Air-pipes, 1080 tons, at $50	54,000
Superstructure, including iron, etc	64,000
Engineering and contingencies	125,000
	$1,948,557

"The above calculation is based upon an excavation of the entire tunnel without any shafting, and would occupy 1556 days. If a central shaft were sunk, thus making four working faces, and dividing it into sections of one and one eighth mile each, it would reduce the time of working to 1054 days.

"It is to be understood that the above computation is made on the old way of working tunnels, without the increased facilities that the *present steam-drills now in use** will give. Should such improvements be made in the present manner of steam-drilling as has been suggested, and illustrated by models to the directors, by some of the best of our mechanical talent, the time and cost will be very materially reduced.

"A. F. Edwards, *Engineer*.

"Engineer's Office, Troy & Greenfield Railroad, North Adams, March 17, 1851."

Still the company were unable to raise the funds necessary in addition to the State loan, the magnitude of the undertaking making it evident that a long time must elapse before a return could be expected for capital invested.

In 1855, a contract was made with E. W. Serrel & Co., under which some work was done, and another was made with them in 1856, for the construction of the road or tunnel, for $3,500,000, they subscribing in stock $440,000. This contract also fell through, as did one made with Messrs. Herman Haupt & Co., in the same year, by which the railroad company agreed to pay $3,880,000 for the completion of the road and tunnel. In 1858, a contract was again made with H. Haupt & Co., by which the contractors themselves agreed "to assume the labor of collecting subscriptions and of carrying on and completing the Troy & Greenfield Railroad and the Hoosac Tunnel." Under this contract, Messrs. Haupt & Co. were to receive the $2,000,000 in bonds of the State of Massachusetts, to be exclusively appropriated to work done upon the tunnel; $900,000 in mortgage bonds of the company, and $1,100,000 in cash, through cash subscriptions and capital stock of the company. Under this contract, the work was vigorously prosecuted up to July, 1861, when a difference arising between the contractors and the State Engineer, a certificate for the amount claimed by the former on a payment was refused, and work thereon was suspended by them. From this time until October, 1863,† the work lay idle where the contractors had left it. In 1862, an act passed the Massachusetts Legislature, providing "for the more speedy completion of the Troy & Greenfield Railroad and the Hoosac Tunnel." Under this act, a board of com-

* The italics are the author's; the reader's attention is called to this matter-of-fact reference to American machine rock-drilling in 1851.

† Senate, No. 50, p. 26, February, 1865.

missioners (Messrs. John W. Brooks, S. M. Felton, and Alexander Holmes) were appointed to examine into the matter on the part of the State. At the request of these commissioners, the Troy and Greenfield Railroad Company, acting under the authority of certain provisions of the act, surrendered to the Commonwealth of Massachusetts, under the several mortgages held by said Commonwealth, the road and property of the company; this surrender having been authorized by the board of directors by a vote passed August 18th, 1862. This action was ratified by a vote of the stockholders, and on September 4th, 1862, the commissioners took possession of the road and its property.

(With regard to the controversy between Messrs. Herman Haupt & Co. and the State, and as to the claims of the firm against the State, it is not in the province of this work to discuss the question.)

The commission, after a full examination of the condition of the road and tunnel, made a thorough report* (dated February 28th, 1863), embracing the three following most valuable sub-reports:

(1) Report of Charles E. Storrow on European tunnels. (2) A report by Benjamin H. Latrobe on the Hoosac Tunnel. (3) A report by James Laurie on the Hoosac Tunnel, and the Troy & Greenfield Railroad. In conclusion, the commissioners recommended that the work should be undertaken by the commonwealth.

At this point, the actual cost of the tunnel to the State (exclusive of interest), from 1854 to the time the State assumed control in 1862, had been $778,695. According to the report of James Laurie, above noted, the condition of the work was as follows:

Whole length of the proposed tunnel, feet....		24,416
Deduct portion already excavated at east end................	2,400	
Deduct portion between present shaft † and proposed western portal of tunnel....................................	1,850	4,250
Leaving to be excavated under the mountain............		20,166

Work was resumed on the tunnel under the auspices of the State in October, 1863, under the control of the same board of commissioners, who appointed Thomas Doane chief-engineer in charge.

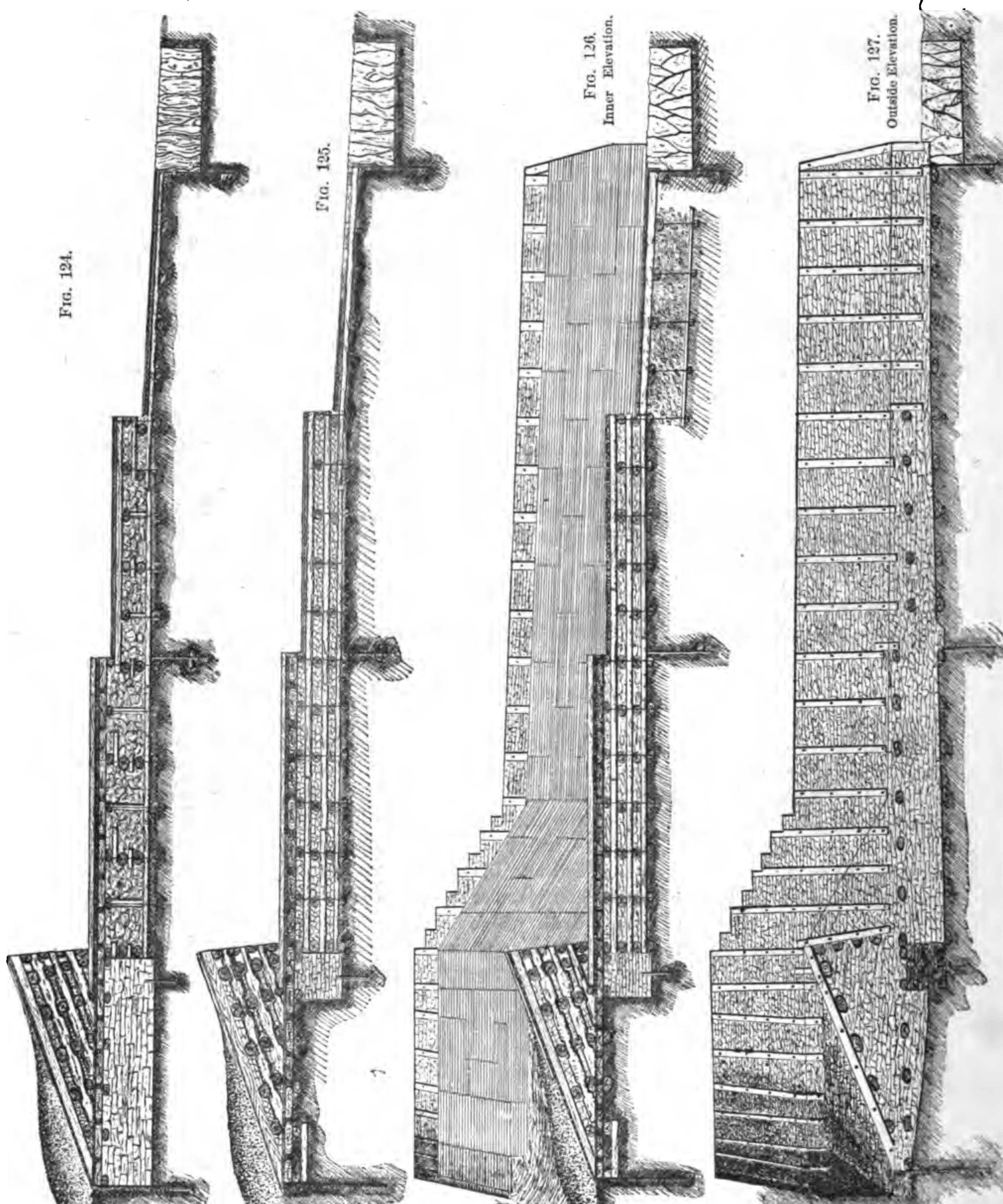
During the continuance of the Haupt contract, and previous to it, various trials had been made with full area tunneling machines, which will be found described in Chapter V., on rock-drills. Also, in that chapter will be found the history of the various rock-drills tried in the early days of the tunnel, and of the Burleigh drill, as finally perfected. Mr. Haupt, during his contract, made an energetic attempt to perfect a percussion-drill, to be used in the tunnel; but owing to the stoppage of his work, his experiments were discontinued, until subsequently carried on by himself in Pennsylvania, independently of the Hoosac Tunnel, in 1864–67. By this time the Burleigh drills, which have since attained so great a reputation, had been adopted and were in full use at Hoosac under the commissioners, and they were retained throughout the subsequent Shanly contract to the completion of the tunnel. (See Chap. V., etc., for fuller notes.)

A dam—Figs. 124, 125, 126, and 127—220 feet in length and 20 in height, was constructed by the commissioners on the Deerfield River. It was completed by June, 1865; from it, water was carried through a canal, at whose mouth a fall of 30 feet was attained, to run turbine-wheels furnishing power for the air-compressors.

During the first year of work of the commission (1864), no advance was effected at the

* Report of Commissioners on Troy & Greenfield R.R. and Hoosac Tunnel, February 28th, 1863, p. 20.

† The shaft here referred to was the "west shaft," 306 feet in depth, sunk by Messrs. Haupt & Co., on the west side of the mountain.



FOUR SECTIONS OF DEERFIELD DAM, HOOSAC TUNNEL (1864-'65). (Scale, 20' = 1').

east heading, of which it will be remembered some 2400 feet had been completed prior to 1863. During this year, the grade of the 2400 feet was lowered, and by December, 1864, the bench of the old workings was reached. This was taken out by March 15th, 1865, and about that time the new heading was started in at the bottom instead of the top as formerly, the new dimensions being 15 feet wide by 6 feet high; the heading located 4½ feet above sub-grade, to give sufficient height for working after the 4½ feet were blasted out and the drain and tracks put in; the idea being to have a culvert or box in the middle of the tunnel. The water accumulating in the tunnel was to pass out on the bottom of this drain; in it were to be laid a 12-inch pipe, to carry air at low pressure, for ventilation only; an 8-inch pipe, to carry air at 60 lbs. pressure for the drills; a 3-inch pipe, to carry water for injecting into the drill-holes; and a 4-inch pipe, to carry gas for lighting. All these early plans were of course much changed and modified subsequently.

On January 1st, 1864, the central shaft was begun; the plan being an ellipse of 27 by 15 feet, with the longer axis lying in the line of the tunnel; area, about 318 square feet. Work was stopped September, 1864, and resumed in the spring of 1865. Rock was reached after about 25 feet of cutting. The sinking of this shaft was continued through the term during which the State Commissioners had charge of the work. It was finally sunk to grade by the Messrs. Shanly during their contract, reaching bottom August 13th, 1870.

The lineal progress of the work will be seen in the tables of progress at the end of this chapter, and on the profile Plate 4.

The west shaft, 8 feet by 13 feet in the clear, and 316 feet deep, had been sunk before the State took possession of the work; work was resumed in the headings, east and west, from its bottom in 1864, the total amount at both sides that had previously been driven at the time of sinking the shaft being about 56 feet.

The following tables* from Mr. Doane's report give a comprehensive summary of the work done in three of the headings driven in 1865.

TABLE 28.

	EAST HEADING.†	HEADING RUNNING EAST FROM THE WEST SHAFT.	
	April 1, 1865, to November 1, 1865. Normal cross-section 6 × 15 ft. Average area = 100 sq. ft.	February 1, 1865, to July 1, 1865. Normal cross-section = 6 × 11 ft. Average area taken as 77 sq. ft.	July 1, 1865, to November 1, 1865. Normal cross-section = 6 × 15 ft. Average area taken as 105 sq. ft.
Days of labor	5,459·00	1,255·00	2,808·00
Drills dulled	117,273·00	10,721·00	35,446·00
Inches of holes drilled	246,138·00	37,792·00	119,220·00
Number of holes drilled	9,634·00	1,699·00	5,017·00
Pounds of powder used	7,680·00	974·00	2,521·00
Feet of fuse used	33,299·00	3,690·00	10,701·00
Pounds of candles used	2,720·00	490·00	1,102·00
Feet of advancement made	411·00	59·00	164·00
Cubic yards of rock removed	1,521·00	169·00	639·00

* Massachusetts Legislative Reports, House, No. 4, pp. 31, 40, 41 (January, 1866).

† The average area in these headings is taken a little larger than the product of the normal height and width would give, to allow for irregularities.

TABLE 28. (*Continued.*)

	EAST HEADING.	HEADING RUNNING EAST FROM THE WEST SHAFT.	
	April 1, 1865, to November 1, 1865. Normal cross-section 6 × 15 ft. Average area = 100 sq. ft.	February 1, 1865, to July 1, 1865. Normal cross-section = 6 × 11 ft. Average area taken as 77 sq. ft.	July 1, 1865, to November 1, 1865. Normal cross-section = 6 × 15 ft. Average area taken as 105 sq. ft.
Giving for one day's labor of one man:			
Drills dulled	21·483	8·544	12·623
Inches of holes drilled	45·090	30·119	42·458
Number of holes drilled	1·764	1·354	1·786
Pounds of powder used	1·406	0·772	0·897
Feet of fuse used	6·100	2·941	3·811
Pounds of candles used	0·498	0·390	0·392
Feet of progress made	0·075	0·047	0·058
Cubic yards of rock removed	0·278	0·134	0·228
Or one foot of advancement required:			
Days' labor of one man	13·291	21·195	17·090
Drills dulled	285·544	181·100	215·739
Inches of holes drilled	599·313	638·377	725·624
Number of holes drilled	23·457	28·365	30·536
Pounds of powder used	18·699	16·451	15·344
Feet of fuse used	81·078	62·331	65·131
Pounds of candles used	6·622	8·281	6·706
Average depth in inches of holes	25·549	22·243	23·763
Average depth of hole in inches cut by each single drill	2·099	3·525	3·363
Average pounds of powder consumed in each hole	0·797	0·573	0·502
Average feet of fuse used for each hole	3·456	2·172	2·133
Holes all drilled 1¾ inches diameter.			

By comparing the last two columns of the above table, we get a ratio between a heading eleven feet wide and one fifteen feet wide, and for it the day's labor of one man is

TABLE 29.

	ELEVEN FEET HEADING.	FIFTEEN FEET HEADING.
One man drills inches of holes	30·119	42·458
" makes feet of advancement	·047	·058
" removes cubic yards of rock	·134	·228

showing that the wider heading gave better results of work. This wide heading had been previously used in the Haupt contract, and we shall see that when the system of machine rock-drilling was perfected during the Shanly contract, the size of the heading was further increased to the full width of tunnel.

In 1866, Mr. Benjamin H. Latrobe was appointed consulting engineer, Mr. Thomas Doane still retaining the position of chief engineer. During this year, machine rock-drills were first regularly introduced into the east heading in June. (For full details of the compressors and drills, and of the Burleigh drill, introduced November, 1866, see Chap. V.)

In 1866, electrical firing with the frictional ebonite battery was introduced by Mr. Doane,* in preference to Shaffner's electro-magnetic system, which had been previously tried under Mr. Doane's direction in 1865. In this year a set of very successful trials of nitro-glycerine were instituted by Mr. Doane, the nitro-glycerine used being imported from

* Massachusetts Legislative Reports, House, No. 30 (January, 1867), p. 21.

Europe, by Mr. Tal. P. Shaffner, who was the first to introduce the Nobel patents into the United States (see p. 65).

The following summary from Mr. Doane's report for 1866 * gives "the average times occupied under the machine-drilling system in the various operations." Mr. Doane says, further, "The blasting has been done once in eight hours, and the averages are made up from data kept through the whole time."

TABLE 30.

1866.	REMOVING ROCK.	PREPARING TO DRILL.	MACHINES DRILLING.	LOADING AND BLASTING.
	h. m.	h. m.	h. m.	h. m.
July	1 08	0 32	5 07	1 13
August	1 08	0 30	5 06	1 16
September	1 03	0 13	5 31	1 23
October	0 54	0 10	5 57	0 59

During the year (1866), the heading driven west from the west shaft was only driven 18·2 feet, reaching a point 298 feet from the shaft. The heading east from the west shaft progressed steadily, attaining a very satisfactory rate of progress, averaging some 49 feet per month. During the year, the following expenditures were incurred at the east heading and at the heading driven east from the west shaft † (according to Mr. Doane's report).

TABLE 31.

	EAST HEADING.		HEADING DRIVEN EAST FROM WEST SHAFT.
	November 1, 1865, to June 8, 1866. (Hand labor and black powder. Area 105 sq. ft.)	June 14, 1866, to November 1, 1866. (Machine drills with black powder. Area 105 sq. ft.)	November 1, 1865, to November, 1, 1866. (Hand labor with black powder. Area 105 sq. ft.)
Days of labor, including foremen	5,476·00	4,350·00	10,101·00
Number of machines sent out	....	979·00	....
Drills dulled	112,489·00	9,336·00	188,505·00
Inches of holes drilled	255,789·00	161,504·00	477,450·00
Number of holes drilled	9,828·00	5,229·00	18,186·00
Pounds of powder used	6,563·00	6,313·00	9,704·00
Feet of fuse	30,202·00	21,951·00	40,896·00
Pounds of candles	2,606·00	2,268·00	3,447·00
Feet of progress made	400·00	191·00	637·00
Cubic yards of rock removed	1,517·00	926·00	2,358·00
Giving for one day's labor of one man:			
Drilling-machines broke down	....	0·225	....
Drills dulled	20·540	2·146	18·662
Inches of holes drilled	46·703	37·123	44·298
Number of holes drilled	1·795	1·202	1·800
Pounds of powder used	1·198	1·451	0·961
Feet of fuse used	5·515	5·046	4·049
Pounds of candles used	0·476	0·521	0·342
Feet of progress made	0·073	0·044	0·063
Cubic yards of rock removed	0·277	0·218	0·233
Or one foot of advancement required:			
Number of drilling-machines working until broken	....	22·718	....
Days' labor of one man	13·674	5·112	15·865
Drills dulled	280·871	48·752	296·066
Inches of holes	638·624	843·363	702·764
Number of holes	24·539	27·305	28·563
Pounds of powder	16·387	32·966	15·241
Feet of fuse	75·410	114·626	64·231
Pounds of candles	6·506	12·842	5·514
Cubic yards of rock removed	3·788	4·835	3·703

* Massachusetts Legislative Reports, House, No. 30 (January, 1867), p. 34. † Ibid., pp. 30, 40, and 41.

TABLE 31. (*Continued.*)

	EAST HEADING.		HEADING DRIVEN EAST FROM WEST SHAFT.
	November 1, 1865, to June 8, 1866. (Hand labor and black powder. Area 105 sq. ft.)	June 14, 1866, to November 1, 1866. (Machine drills with black powder. Area 105 sq. ft.)	November 1, 1865, to November 1, 1866. (Hand labor with black powder. Area 105 sq. ft.)
Average depth in inches of holes	26·025	30·886	24·604
Depth of hole in inches cut by each single drill	2·274	17·299	2·374
Pounds of powder consumed in each hole	0·668	1·207	0·533
Feet of fuse used for each hole	3·073	4·178	2·249
Depth of holes cut by each drilling-machine	....	164·968	....
Number of holes cut by each drilling-machine	....	5·341	....
	Holes 1$\frac{3}{8}$ inches diameter.	Holes 1$\frac{1}{4}$ to 1$\frac{5}{8}$ inches diameter.	Holes 1$\frac{3}{8}$ inches diameter.

A supplementary shaft to the west, 277 feet deep, was sunk during 1866, at a point 264 feet west of the west shaft, in order to give a longer base-line for the surveys running east. It was deemed imprudent to continue the long line east from the west shaft with so short a base as the mere width of the shaft, 8 feet. The supplementary shaft was made 6 by 13 feet in clear, the 13 feet being at right angles to the tunnel line.

During the summer of 1864, the decomposed rock of the west end was first met in open cut. Subsequently, borings were tried to ascertain the nature of the material between the west shaft and the west end. Owing to the nature of the ground, these borings did not succeed well, and four test-pits or wells were sunk during 1865–'66, as follows:

TABLE 32.

WELLS OR TEST-PITS.	No. 1.	No. 2.	No. 3.	No. 4.
Distance from west shaft (in feet)	2091·0	1976·0	1713·0	924·0
Surface above sub-grade	79·5	118·0	134·0	315·0
Depth of well	38·0	51·0	67·0	103·0
Depth of boring below well	43·5	50·0	68·0	.....
Reaching a point above or below sub-grade	—2·0	+16·0	—1·0	+102·0
Top of decomposed rock below surface	13·0	46·0	67·0	None
" " " above grade	66·5	71·0	67·0	"
" solid " below surface	None	None	one	"
" " " above sub-grade	"	"	N"	138·0

In this year (1866), also, the masonry at the west end was given on contract to Mr. B. N. Farren, who effected a total advance of 131·5 feet from August 9th, 1866, to November 1st, 1866.

In the Commissioners' Report for 1866, Mr. B. H. Latrobe's first report as consulting engineer is embodied.

In 1867, Mr. Doane resigned as chief-engineer.

So many able and distinguished engineers and contractors have, during the progress of the Hoosac Tunnel, contributed in a greater or less degree to its final success, that it would be out of place in a record such as this purports to be for the author to attempt to give especial credit to any, where so much was done by all, in the work of the tunnel proper. But Mr. Doane's connection with the Hoosac Tunnel in the early days of that great work is not a matter of especial, but of universal, interest to the engineering profession in America; for to his persistent energy, his far-seeing sagacity, and his able management, we in a large meas-

ure, and in fact chiefly, owe the development and introduction into this country of the present advanced system of tunneling with machinery and high explosives; it was under his direction, as engineer of the commission, that the State experiments were made, and the long and disheartening fight carried through which terminated in favor of the new system, the system which has since given us the Burleigh, Ingersoll, and Wood drills, and which also first showed Americans practically what the potent agency of nitro-glycerine first applied by Nobel in Europe in reality was.

Mr. W. P. Manning was appointed to the position resigned by Mr. Doane. Mr. Manning also resigned after a tenure of a few months, and the work was conducted through the year under the charge of Alvah Crocker, as resident commissioner. Mr. Benjamin H. Latrobe still continued in the office of consulting engineer. After the resignation of Mr. Manning, there was no chief-engineer appointed, Mr. W. P. Granger acting as resident engineer. The work from August 1st to November 1st was prosecuted under contract by Messrs. Dull, Gowan & White, except the west end arching, which had been let to Mr. Farren during the previous year. In April,* 1867, Mr. Farren also took a contract to drive an adit between the west end and the heading driven west from the west shaft. It was started 4½ feet wide at bottom, 3½ wide at top, and about 6 feet high in the clear, above the drain. In October, 1867, owing to the accidental lighting of some naphtha at the central shaft head house, the buildings and shaft were consumed, and thirteen lives lost.† Owing to this accident, the contractors voluntarily surrendered their contract, received their pay, and returned the work to the hands of the commissioners. By inspecting the table of progress at the east end during this year (Table 42, p. 373), it will be seen that from June on the progress reached a point higher than any rate ever previously attained at the tunnel. This is ascribed in the Commissioners' Report to the adoption of the improved Burleigh drill. During the year, Mr. Farren completed 350 feet additional of brick tunnel.

During July and August, 1867, the west heading was raised from bottom to top. In July, Alvah Crocker, commissioner in charge of the work, called Mr. George M. Mowbray to North Adams to furnish nitro-glycerine. The matter, however, was not matured until after the termination of Dull, Gowan & White's contract.

The whole number of men employed on the tunnel January 1st, 1868, was: East end, 210; central shaft, 32; west shaft, 172; west end, 86; engineer's roll, 9—total, 509.

In the report of the consulting engineer,‡ Mr. Benjamin H. Latrobe, for 1867, occur the words: "For my own part, I have never wavered in my opinion that the contract system is the only one by which the work can be done with economy and expedition combined. The unfavorable results, in some respects, of the contract with Messrs. Dull, Gowan & Co. have not in the least shaken this conviction." . . . "The work done under their contract has, with an exception to be duly noticed, cost the State very greatly less than similar work executed by herself, notwithstanding all the commendable efforts which have been made by the commissioners to cheapen the operations conducted by day labor under their immediate direction. Thus the heading at the east end, for which the contractors received $7.25 per cubic yard, cost the State, for the part done by her, $24.46 per cubic yard, or nearly 3⅓ times the contract price. I am told, indeed, that Messrs. Dull, Gowan & Co. represented themselves as losers by their price for this part of the work, and requested to have it increased to

* Massachusetts Legislative Reports, Senate, No. 20, January, 1868, p. 17.

† An accident bearing some resemblance to this occurred at the Hauenstein Tunnel in Switzerland in 1857. In the latter case, owing to the burning of a shaft, some fifty-two miners were inclosed in a drift, and suffocated by foul air. (Massachusetts Legislative Reports, House, No. 355, 1868. See also p. 51 of Mr. Chas. S. Storrow's report, above referred to.)

‡ Massachusetts Legislative Reports, Senate, No. 28, January, 1868, p. 50.

$11 per yard. If so, and the increase had even been made (which I would not have recommended) the cost to the State under the contract so modified would have been less than half what it was costing her in the other way. . . . . The single item in which the cost per cubic yard of State work falls within the contract price of Dull, Gowan & Co. is that of excavation at the central shaft, which seems to have cost but $22.59 as done by the commonwealth, while the contractors received $25 per yard. The difference of $2.42 is less than an ordinary margin for contingencies and profit on contract work, and much, if not all of it, might well be absorbed by the increased cost of the work as the shaft deepened.

"The steady progress of the arching at the west end, and the great reduction of cost thereat, as compared with the previous execution of the same work by the State, notwithstanding the very liberal prices paid the contractor, should recommend the contract system for all other parts of the work, proper care being taken that able and reliable contractors are employed in every case. Until this system is adopted and consistently adhered to, all estimates of the ultimate cost of the work will be worse than useless, because they may mislead the State, who has taken the enterprise upon herself."

In October, a clear connection was effected in the headings between the west shaft and the west end of the tunnel.

During the year 1868, Mr. Benjamin D. Frost was appointed superintending engineer in May.*

It will be remembered that a set of four prospecting shafts were sunk by Mr. Doane at the west end in 1865–'66. In September, 1867, Mr. Crocker commenced sinking one of them, Well No. 4, down to grade. It was then 103 feet deep. This well reached grade (215 feet deep) in April, 1868, and headings were then commenced both ways. On July 7th,† connection was made with the heading driven west from the west shaft, and in October, 1868, this heading continued on west from the west shaft, met the adit driven east from the west end, thus affording connection throughout, and a clear flow for the water from the heading driven east from the west shaft.

Machine-drills were introduced into the east heading of the west shaft in June, 1868, and nitro-glycerine in August. In the month of September, a linear advance was attained of 51 feet for five sixths only of the full month's work. The two carriages used were larger than those at the east end, and intended to carry five drills each. (It will be remembered that this heading was raised from bottom to top in July and August, 1867.) In Mr. Benjamin D. Frost's report for 1868,‡ in speaking of the use of nitro-glycerine, he says:

"Its superiority over the powder ordinarily used in blasting, as demonstrated by our own experience, may be briefly expressed in the following items:

"1. Less number of holes drilled in proportion to area of face carried forward. Estimated saving, 33 per cent.

"2. Greater depth of holes permissible. Average depth for nitro-glycerine, 42 inches; for blasting powder, 30 inches.

"3. More complete avail of the full depth of hole drilled."

(Simultaneous blasting by electricity used.)

On December 24th, 1868, a contract for the completion of the Hoosac Tunnel was finally given to the firm of Shanly Brothers, of Montreal, Canada, for the full sum of $4,594,268, the tunnel to be completed by March 1st, 1874, the governor and council having authority to extend the time, if necessary, six months longer.

According to the statement of the Commissioners on the Troy & Greenfield Railroad and Hoosac Tunnel, as cited in Mr. Latrobe's report to the Governor for 1868,* the cost of

* Massachusetts Legislative Reports, House Doc. No. 192, March, 1869, p. 58. † Ibid., p. 61. ‡ Ibid., p. 66.

the tunnel to the State up to December 31st, 1868, had been in all $3,002,176. This amount being paid directly from the State appropriations, beginning with the one of $2,000,000 in 1854, and being exclusive of the amounts paid for the construction of the Troy & Greenfield Railroad, and for the Southern Vermont Railroad. It was therefore estimated that the final cost of the tunnel, exclusive of engineering and other incidental expenses, would be:

Total cost to December 31st, 1868	$3,002,176
Amount of contract with Shanly Brothers	4,592,000
Total estimated cost of Tunnel, Jan. 1869	$7,594,176

There had also been to date, in addition to this expenditure of $3,002,176 for the tunnel, an additional amount of $1,500,922 paid out by the State from 1854 to December 31st, 1868, on the construction of the Troy & Greenfield Railroad, and for the purchase of the Southern Vermont Railroad.

The Shanly contract was mainly as follows: Dimensions of the tunnel, in rock, without arch, 24 feet wide by 20 feet high in the clear; where arching required, 26 feet wide by 21½ feet high above the rail in the clear. A central drain to be constructed as required, with dimensions inside of masonry of not less than 2 feet square.

The average rate of progress to be kept up, to be: (1) tunnel enlargement, 75 feet per month; (2) heading enlargement, 75 feet per month; (3) extension of full-sized tunnel, 125 feet per month; (4) excavation and construction of central drain, and laying pipes through the tunnel, 150 feet per month, or not more than 500 feet behind the advanced heading.

The bid of Shanly Brothers was in a gross sum for the whole amount of $4,594,268; but arrangements were made for certain rates to be paid on the monthly estimates, as will be seen by consulting their contract.

At the end of 1868, Mr. Benjamin H. Latrobe resigned his position as consulting engineer. In his report† he says:

"The policy of the contract system for the further prosecution of the tunnel to completion, which my previous reports will show me to have recommended, having been adopted by the Legislature in their act of June 11th, 1868, and the work having been contracted for with parties whose testimonials of character afford every reasonable assurance that they will perform what they have undertaken, and whose financial ability will be thoroughly tested by the reservation of the large amount which they have agreed to leave in the hand of the commonwealth as a guarantee, I think the difficulties which have attended this great enterprise may be considered practically at an end. Vast as is the magnitude of the work, it has not, in fact, presented physical obstacles as formidable as those which have embarrassed many other undertakings of similar work.

"The 'demoralized rock,' as it has been called, at the west end, was indeed a troublesome feature, but not so bad as the quicksands and slippery clays of some of the English tunnels. The water in the west shaft required only good pumps and ample power to keep it down. The central shaft has been dry and attended with no drawbacks, except those which casualties that might have been avoided with ordinary care have produced; and, lastly, the east end has been as straightforward and really *comfortable* a piece of underground work as could be wished for. The real difficulties of the enterprise have been due chiefly to other causes of an extraneous character, to which, as it is hoped that they are now no longer in action, it is not necessary to refer more particularly."

* Senate No. 6 (1869), p. 10. † Ibid., p. 6.

All work on the tunnel had been suspended * previous to January 1st, 1869, excepting the prosecution by B. N. Farren of his unfinished contract for the construction of a portion of the brick arch at the west end. This he completed early in February, 1869, and the work was taken up by Shanly Brothers in April following.

Early in March, 1869, Shanly Brothers were ready to go on with their work, commencing excavation at the east heading March 29th, at the central shaft (sinking) May 20th, at the west end heading July 2d, and by December they had a force of about seven hundred men at work in all.† Though the articles of agreement had been made between Shanly Brothers and the State on December 24th, 1868, still the completion of their negotiations with the agent of the commonwealth appointed for the transfer and sale of State property was not attained until March 26, 1869. On August 13th, 1870, the central shaft reached tunnel level; from this date to October 25th, 1870, there was no advance made from the bottom of the shaft, the time being taken up in trimming down its sides and in repairing and strengthening the timbering and guides, etc. A heavy rain-storm‡ on October 3d and 4th, 1869, did much damage to the workings at the west end, where operations had to be stopped entirely from October 4th to 25th in consequence. The principal damage was caused by the sudden swelling of a brook which had formerly crossed the line of the railroad about 350 feet west of the tunnel portal, but which had been diverted by excavating a new channel parallel with and some 150 to 200 feet north of the line of the railroad. This stream being swollen by the rain, suddenly undermined its banks, and, forming a dam of *débris*, backed into the tunnel, and so sudden was the rise that in one and a half hours the water had risen 15 feet above the brick arch at the mouth, and backed up through the arched tunnel and driftway beyond into the workings east of the west shaft, filling them as far as the advance heading; all the men escaped but one, who was caught in the tunnel and drowned. So tight was this *débris* dam that by October 13th, the water was still one foot above the top of the brick arch at the west portal, in spite of all that could be done by a large force which the contractors put to work immediately on October 5th. At the east end no serious damage was done by the rain, the work being only interrupted one day.

During 1870, "the improved Burleigh drills gave highly satisfactory results." § Mr. Walter Shanly says of them: ‖ "The use of the Burleigh drill saved about two thirds of the expense of drilling. The expense of labor would have been, I think, fully three times the cost of machine-drilling. To have done this work by hand-drilling would have taken, I should estimate, not less than twelve years." In 1870 nitro-glycerine was in general use throughout the work. Later, during 1874, mica powder (see p. 88) was largely substituted for pure nitro-glycerine, especially for roof-holes, and in taking up the bottom or bench. During five years' time, about 444,735 lbs. of nitro-glycerine and about 100,000 lbs. of mica powder were used by the Shanly Bros. Dynamite was tried on several occasions, but preference was given to pure nitro-glycerine and mica powder, both being manufactured in the vicinity by Mr. Geo. M. Mowbray.

It being now deemed expedient for the State to again have a consulting engineer, Mr. James Laurie was appointed by the governor on May 8th, 1871, Mr. Frost still continuing to act as superintending engineer. The work now went on steadily to its completion: as the system of applying power-drills became better understood, the rates of progress of course became greater. The centre-cut system of blasting (explained fully in the description of the

* Report of Joint Standing Committee for 1869. Senate, No. 58 (1870), p. 4.

† Ibid., p. 10.

‡ Senate, No. 283, 1871, p. 11.

§ Report of Consulting Engineer, Senate Doc. No. 283 (1871), p. 25.

‖ House, No. 375, May, 1874, p. 26.

Musconetcong Tunnel, p. 309), was developed and the general rates of work will be seen in Table 42, etc., and on Pl. IV.

Fig. 128 shows a general plan of the compressors and machinery used at the central shaft, and Fig. 129 is a bench-carriage employed to hasten work by breaking up the bottom at intermediate points. The regular bench-carriage used both at Hoosac and Musconetcong has been shown (Fig. 120).

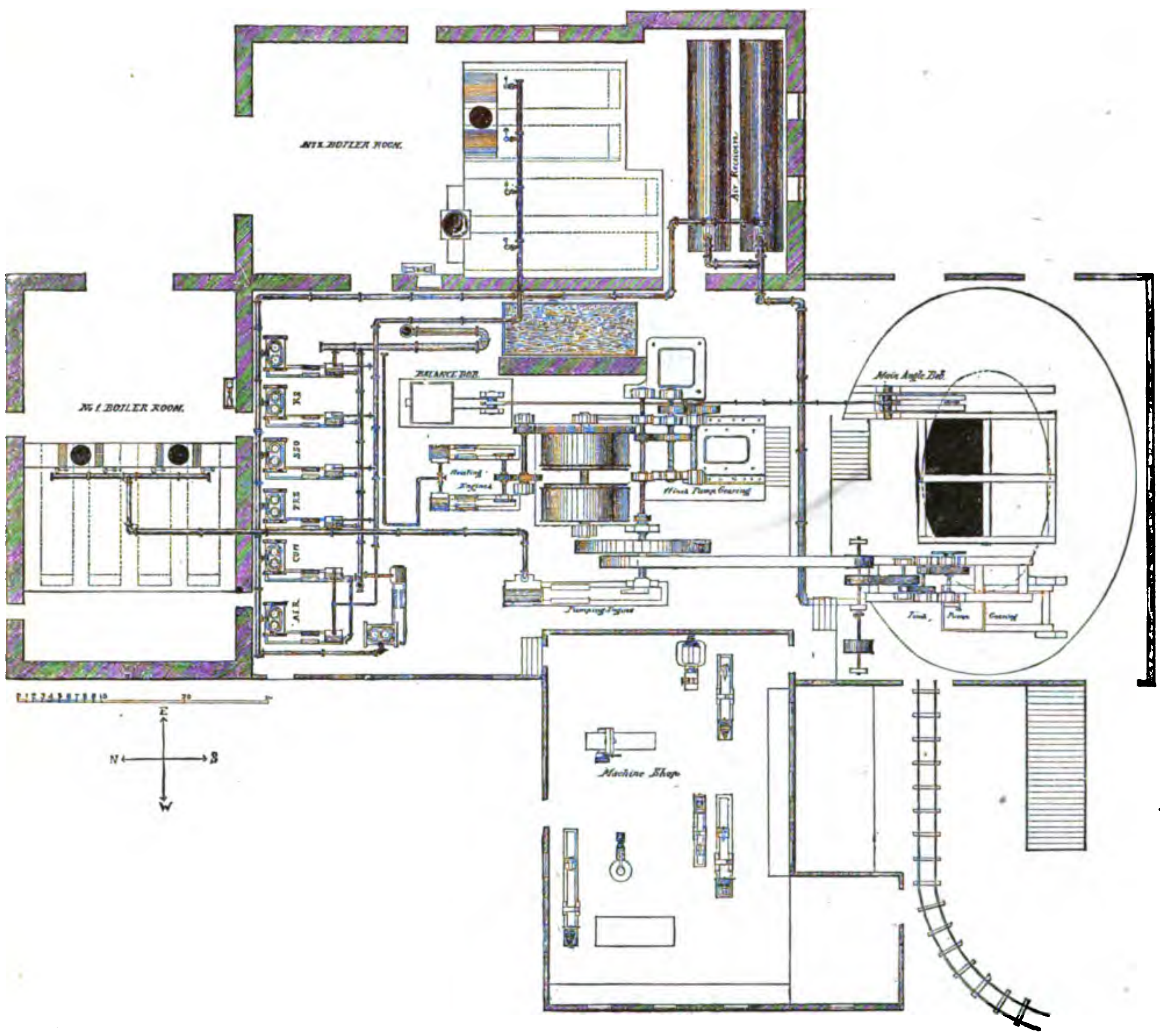


FIG. 128.

GROUND PLAN OF THE BUILDINGS AND MACHINERY, CENTRAL SHAFT, HOOSAC TUNNEL.

Finally, the east heading met the one driven east from the central shaft on December 12th, 1872, and the west heading met the one driven west from the shaft on November 27th, 1873: the errors in alignment and levels being astonishingly small.

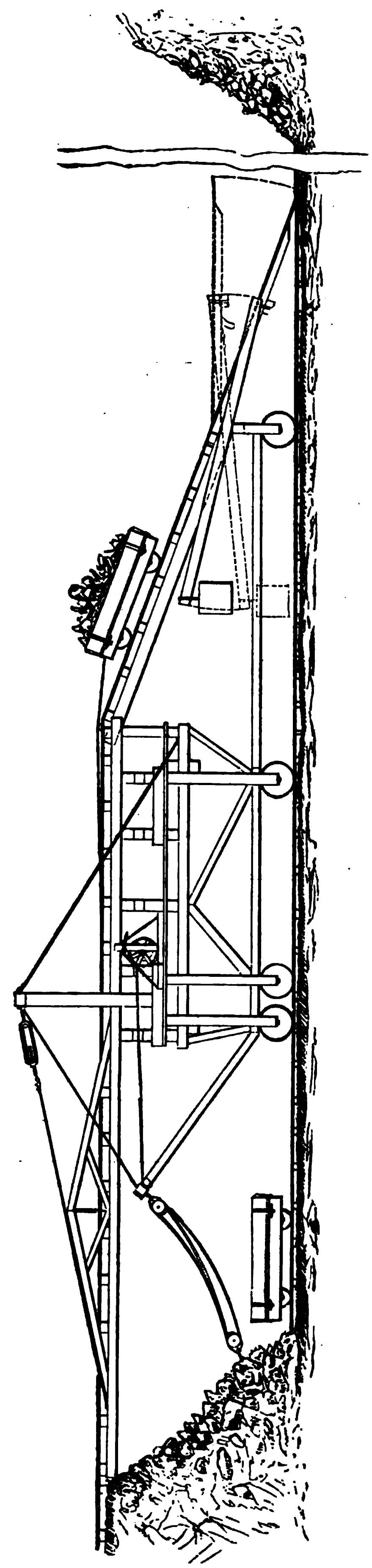


FIG. 129.

CARRIAGE USED AT HOOSAC TUNNEL FOR CARRYING ROCK AWAY FROM AN INTERMEDIATE BREAST OF WORKING.

Scale, 10' = 1".

The following short table* will show concisely the amount of heading driven yearly by Shanly & Co.:

TABLE 33.

ADVANCE OF HEADINGS.	1869.	1870.	1871.	1872.	1873.
From east end	1239	1514	1743	1495	....
Central shaft { east	....	60	277	1226	....
Central shaft { west	....	87	158	119	1697
West end	449	1203	1380	1616	1435
Aggregate lineal feet	1688	2864	3553	4456	3132
Total amount of headings driven by Shanly & Co.					15,693

Prior to this time, on February 7th, 1871, Mr. Edward S. Philbrick had been appointed State Consulting Engineer in place of Mr. Laurie, resigned.

As the headings east and west from the central shaft were not commenced until October 25th, 1870, it will be seen that the alignment of these headings, probably the most difficult and delicate task recorded in the annals of tunnel-surveying, was conducted during Mr. Philbrick's incumbency and under his supervision as State Engineer. On February 8th, 1875, Mr. Philbrick resigned, on the completion of the Shanly contract, the work on which he had been consulted having terminated. From this time on, the only work that remained to be done was the completing of the arching; and where the services of a consulting engineer were required, Mr. Thomas Doane, who, it will be remembered, as chief-engineer designed the original arched section in 1866, was consulted by the governor.

The Messrs. Shanly concluded their contract and effected a provisional settlement December 22d, 1874. Independently of the contract taken by them, an agreement was entered into between the State and B. N. Farren on November 19th, 1874, to do certain enlarging and arching at the eastern portal of the tunnel. The working profile Plate 4 shows the portions of the tunnel finally lined, with the dates at which the work was done.

By authority of an act passed in 1874,† five experts, viz., Prof. T. Sterry Hunt, of Boston, and Prof. James Hall, of Albany, as geologists, and Thomas Doane, Josiah Brown, and Daniel L. Harris, as engineers, were appointed to examine and report separately on the amount of arching that would still be necessary. The total amount of arching recommended by them throughout the tunnel at various points was as follows‡ (these amounts include in each case, under the column "Safe," the amount of tunnel previously arched by Farren and by Shanly Brothers, amounting in all to 2410 feet):

TABLE 34.

NAME OF EXPERT.	LINEAL FEET.								
	Safe.			Trim.			Arch.		
	West of Central Shaft.	East of Central Shaft.	Total.	West of Central Shaft.	East of Central Shaft.	Total.	West of Central Shaft.	East of Central Shaft.	Total.
James Hall	5651	9036	14,687	2200	295	2495	4393	3506	7899
T. Sterry Hunt	9394	10,443	19,837	655	....	655	2195	2394	4589
Josiah Brown	6865	9725	16,590	....	....	....	5379	3112	8491
D. L. Harris	4550	9450	14,000	....	....	....	7694	3387	11,081
Thomas Doane	2518	7991	10,509	5873	2417	8290	3853	2429	6282
Average	5796	9329	15,125	2909	904	3813	4703	2965	7668

* Report Joint Standing Committee, Senate, No. 201 (1874), p. 18.

† Sec. 5, Senate Doc. No. 361, 1874.

‡ House, No. 9, Jan., 1875, App. I., p. ix.

These reports were all made in October of 1874. Previous to this date, an examination had been made by the consulting engineer, Mr. Edward S. Philbrick, with the superintending engineer, Mr. B. D. Frost, and, in a report dated July 1st, 1874, Mr. Philbrick gave as his opinion that * "there will be certainly required, for the safe passage of trains, a further amount of 1600 feet of arching;" also Mr. Philbrick speaks of a still further length of 3550 feet, concerning which at that date he could not give a positive opinion; that there was further a length of some 20,500 feet which required to be carefully gone over and sounded, and the loose pieces detached, the rock having become loosened since the original excavation was made, owing to veins of talc and feldspar intersecting the mica-schist, which gradually became decomposed by the action of percolating water. The rock besides, especially west of the central shaft, was very seamy, cutting the mass into detached blocks, having little or no cohesion, and carrying large quantities of water. The total amount finally arched will be seen on the profile, Plate 4.

Under the law of 1874, a board of corporators of the "Boston, Hoosac Tunnel & Western Railroad" was created: they, in their report for 1874,† put the cost of the tunnel to the State up to date at $14,000,000: this, however, includes the sums expended on the railroads connecting with it, and is not the figure for the tunnel alone.

By a subsequent act of 1874,‡ the corporators were superseded by five directors, to whom the interest of the State in the tunnel and railroad was transferred.

By the Report of the Joint Special Committee§ of the Massachusetts Legislature, dated April 20th, 1877, the following final summary is given of the history and cost of the tunnel: "Work was commenced upon the tunnel in 1854. Total length of tunnel and Troy & Greenfield Railroad = 44 miles. Work upon the tunnel was prosecuted by the Troy & Greenfield Railroad Company, with the assistance of State loans, until September 4th, 1862, when the State took possession, and, except a small portion, completed the work July 1st, 1876. Opening made through the mountain, November 27th, 1873." (The first engine was run through the tunnel February 9th, 1875; its name was the "N. C. Munson," and it was run by Thomas Doane). "The first passenger-trains began to run through the tunnel October 13th, 1875. At this date, arching and other work was still going on: the first freight-train ran through from the west April 5th, 1875, and the tunnel was declared completed and open for business July 1st, 1876. The total cost of the Hoosac Tunnel and Troy & Greenfield Railroad to the State, up to January 1st, 1877, was $17,322,019. Of this total cost, the amount of $3,287,835 is interest; so that, without any regard to the sinking fund, the actual cost of the Hoosac Tunnel property" (including the railroad), "exclusive of interest paid, up to January 1st, 1877, amounts to $14,034,185."

Now, it must be borne in mind that this figure represents the cost of the "tunnel property" so called—in other words, besides the tunnel, it covers the cost also of some 44 miles of railroad; it also includes $200,000 paid for the purchase of the Southern Vermont Railroad.

Going back a little, we see (p. 327) that the figure for the cost of the tunnel alone,

up to the Shanly contract, was..	$3,002,176
In addition, we have amount of Shanly contract as per bid.....................	4,594,268
Additional payment (over and above contract price) to Shanly Brothers, as per Resolution,‖ Acts 1875, Chap. 73......................................	131,000
	$7,727,444

* House, No. 9, Jan. 1875, App. I., ix. † House, No. 9, 1875, p. 23. ‡ Ibid., p. 3. § Senate Doc. No. 170, p. 5 (1877).

‖ This was an additional sum voted by the Legislature to be paid to Shanly Brothers, in consideration of unlooked-for losses, incurred in carrying on the work. Shanly Brothers claimed to have made nothing on their contract, but, in fact, to have suffered a loss of some $226,000, owing to losses from floods, cost of additional arching required, etc. etc. (See Senate Doc. No. 150, p. 2, 1875.)

Carried over from last page $7,727,444

Now, besides this amount there were paid, according to the Auditor's Report.*

In 1869, to B. N. Farren, on contract	$37,966	
Engineer's pay-roll, assistant's expenses, etc., from 1869, inclusive, to January 1st, 1877	320,627	
In 1874, B. N. Farren, contract	5,883	
" 1875, " " "	562,127	
" 1876, " " "	604,456	
		1,531,059
Giving a total of		$9,258,503

It would therefore appear that, allowing a margin of about $750,000 to cover other general expenses incurred since the termination of the Shanly contract (salaries, materials, etc. etc., in finishing up the work), we can still with tolerable safety assume $10,000,000 as the cost in full, without interest, of the tunnel proper. This estimate will leave a balance in round numbers of $4,000,000 expended on the railroad, and other collateral matters, etc.; and as we saw (p. 327) that the cost of the road up to December 31st, 1868, had been about, say, $1,500,000, † the balance of $2,500,000 can be taken as the total expended in the completion of the railroads by the State from January 1st, 1869, to the end. (This estimate of the total cost of Hoosac, prepared by the author from the State reports, has been submitted to and approved by Mr. Thomas Doane.)

This finishes our history proper of Hoosac.

By consulting Table 42, etc., and the profiles (Plates 3 and 4), detailed statements will be found as to rate of progress, geological formation, etc. etc. The subject of the rock-drills and compressors used will be found more fully noted in Chapter V.

The following notes regarding the rock-drilling at Hoosac have been prepared especially for this work by Mr. Walter Shanly, since the completion of his contract. They are the fullest and in fact the only record ever published of the cost of rock-drilling at Hoosac during the Shanly contract, when, as we have seen, the main body of the tunnel was driven. (The figures, it should be remembered, refer to *heading* work. They therefore are more costly, and cannot be fairly compared with estimates of total cost of heading and bottom work taken together in other tunnels.)

Relative Cost and Rate of Progress of Hand and Machine Labor in Headings: from Notes of Work at Hoosac Tunnel.

"Office of Walter Shanly, Civil Engineer,
Montreal, Canada, June 20, 1877.

"Henry S. Drinker, Esq., C.E., Philadelphia:

"Dear Sir: I have pleasure in responding to your request that I would state what may be the difference in cost of rock-drilling, and also in time gained, as between *machine*-work and *hand*-work, based on my experience in the Hoosac Tunnel.

"I concur with you in thinking that in point of money economy there is nothing to be

* April, 1877, Senate, 180, p. 10, etc.

† Senate, No. 6, p. 10 (1869).

gained by applying machinery to the driving of *short* tunnels generally; but one cannot very well fix an arbitrary line at which 'short' shall end and 'long' begin. I observe that you incline to place the dividing line at 2000 feet; tunnels over that length to be classed as *long* and worked by machinery. Local conditions must largely govern in deciding on the use or non-use of power-drills. Favoring aspects of *power*, such as the proximity, abundance, and easy applicability of a good head of water, might render it judicious to drive a tunnel of much less length than your limit of 'short' by machine- rather than hammer-work.* Of course where *time* is the primary and *cost* a secondary consideration, mechanical appliances might have to be resorted to for almost any length of boring—1000 feet, or less even—especially in cases where work would necessarily have to be carried forward on two faces only. In the Hoosac Tunnel I used both water and steam—*i. e.*, applied both kinds of power to the compressing of the atmosphere, which third power, manufactured outside the tunnel, was sent to the drills inside under a pressure of from 60 to 64 pounds on the square inch. The rock pierced in the four and three quarter miles through Hoosac Mountain differed materially in structural character on the opposite slopes. The easterly half was a uniform mica-schist largely permeated with, and at intervals intersected by, veins or seams of pure quartz. It was a fairly good rock to drill, but somewhat tough of breaking. The westerly half of the work was in ground of varying character—passing from hard granite to granitoid gneiss, with much feldspathic and quartzose formation of exceeding hardness. The whole uniform in the one condition only of being extremely wearing upon tools and requiring deep drilling and heavy doses of nitro-glycerine to bring it out. At the easterly end of the tunnel, from which 'base' the best of the rock was to be attacked, I had water-power for compressing the atmosphere. The western workings were wholly dependent upon steam, causing, as you will perceive from the figures I give you below, a very marked difference in the expense of *manufactured power* as compared with that obtained through the agency of water at the other end, and which, in conjunction with the greater hardness of the rock, created a wide want of accord between the cost of drilling in the two divisions of the work.

"In estimating the cost of machine-drilling, I have included mining labor, mechanical labor, blacksmith-work, materials consumed—such as iron, steel, oil, steam-coal, forge-coal, etc. etc., and also allowed for interest on and depreciation in value of 'plant.'

* This reference of Mr. Shanly's is to a letter from the author to Mr. Shanly, in which the author expressed the opinion that, as a general rule, machine-drilling would not pay in short tunnels—that the gain in time would not pay for the outlay for plant. Of course, in such a matter, no arbitrary limit can be laid down; as Mr. Shanly justly observes, local considerations will necessarily exercise a controlling influence; but, except where especially favorable circumstances occur, the author is willing to abide by the opinion that at the present rates of cost, and in the light of past experience, the use of machines in railroad-tunnels under 2000 feet in length will not be found to promote ultimate economy of work. This is largely owing to the fact that in every new railroad-tunnel of the present day, the contractors and their hands have all to learn anew the art of drilling with machinery. When in the future the use of machine-drills becomes familiar to the great class of tunnelmen, so that so much time and money in each new tunnel need not be expended in taking costly lessons from new experience, then, probably, we shall find it economical to apply drills even in the shortest tunnels. Now the question is not, Can Shanly, or Steele, or McFadden, or Sutro, drive short tunnels to good effect with power-drills; but, Can the average contractor, who has never used them in former tunnels, do so? In February, 1876, the author asked Mr. Sutro what length of tunnel, in his opinion, ought to limit the introduction of machinery? His reply was, "That depends upon the hardness of the rock. I would not think of introducing machinery under any circumstances in a tunnel less than 1500 feet, that is accessible from both ends, and probably in a tunnel of that length it would hardly pay to go to the expense of erecting the proper compressing machinery, drill-carriages, etc. etc. It may be stated as an engineering proposition that in rock of average hardness, it would not pay to introduce machine-drills in a tunnel of less than 2000 feet."

(These observations, of course, apply chiefly to railroad-tunnels. In a mining region, where many successive short tunnels have to be driven, it may be found to pay well to use machinery on comparatively small pieces of work; for here the machinery is in constant use, and not laid aside on the completion of a single tunnel.)

In the Easterly workings, the power-drilling cost per inch		4 cents ($3\frac{99}{100}$)
Apportioned—Mining labor and supervision	$.02\frac{33}{100}$	
Mechanical department	$.00\frac{65}{100}$	
Blacksmith-work	$.00\frac{45}{100}$	
Materials consumed	$.00\frac{21}{100}$	
Interest and depreciation 10%	$.00\frac{35}{100}$	
Hand-drilling in same ground cost		$9\frac{33}{100}$ cents.
In the Westerly workings, the inch-cost of power-drilling was		$7\frac{10}{100}$ "
Apportioned—Mining labor and supervision	$.03\frac{38}{100}$	
Mechanical department	$.01\frac{45}{100}$	
Blacksmith-work	$.00\frac{65}{100}$	
Materials, including steam-coal	$.01\frac{80}{100}$	
Interest and depreciation, 5%	$.00\frac{37}{100}$	
And in the same place and ground, hammer-work would have cost		13 "

"These instances all refer to drilling in the 'headings'—strictly *tunnel* work—and the results are obtained by taking in each case the average of three average months. It is also to be noted that the work was carried on during a period (1869–1874) of high 'inflation' prices for every thing: Mining labor, \$2.25; mechanical labor, \$3 to \$3.50 a day; machinery, hedged in by patent-rights and royalties, charged at far above its just market value; and coal, at the furnace-mouth, reaching to nearly ten dollars the ton. In respect of *time saved* through the use of machinery, the greatest advance I ever made in any one month in the mica-schist was 167 feet; and in the westerly slope, where, as was not unfrequently the case, the hard rocks broke well, I have advanced in 26 working days as much as 184 feet. In the mica schist there has been made in a month's work by *hand-labor* an advance of 40 feet; while in the granitic and quartzose rocks it would have been hard by same process to reach 30 feet. Altogether, I incline to place the advantage in gain of time between machine-drilling and hand-drilling at from four to five to one in favor of the former. In coping with rocks such as those composing Hoosac Mountain, and driving large headings—24 by 7 feet—as was done there, such rate of progress as you instance being made in the Sutro and St. Gothard Tunnels —300 feet per month—is not to be effected by any means or appliances that I have yet seen or read of.*

Breaking of Rock.

"In the schist we drilled, on an average, to every cubic yard of rock blown out, about 133 inches; in the granite and quartzose formations, from 100 to 140 inches, the average of 36 months' working showing 130 inches per cubic yard. In the former (the schist), ordinary 'cannon' powder was the explosive applied, about 5 pounds being needed to bring out a cubic yard of rock. For the other rocks, westward of the central shaft, Mowbray's tri-nitro-glycerine was none too powerful a motive agent—in charges of from $2\frac{1}{4}$ to $3\frac{1}{2}$ pounds per cubic yard: holes 2 inches in diameter, and from 8 to 13 feet in depth. In calculating the amount of drilling done and explosives used to each cubic yard of rock removed, I have taken into account the *net* quantities within the prescribed areas of work only; but there was always more ground actually broken and removed than the prescribed measurements embraced —about one eighth more all round; so that the true quantities of material affected by both

* It should be noted here that the St. Gothard heading is driven with a much smaller sectional area; at Hoosac and Musconetcong the whole enlarged top heading (or "calotte" of the Europeans) was driven at once by the centre-cut system of blasting, with no "Galerie de Direction" (Richtstollen) whatever.

drilling and blasting are greater, and the proportions of these last due to each cubic yard removed consequently so much less than my figures indicate.

Example of duty performed by machine (Burleigh) drills in the "headings" of Hoosac Tunnel, from the results of 10 "shifts," steady working, time and measurements carefully ascertained, in August, 1873.

"The drilling was in rock of medium hardness, a gneiss very near akin to actual granite; not nearly so severe on drills and steel as the quartzose rocks being penetrated at the same time on another face of the work, but many degrees harder than the mica-schist prevailing in the easterly slope of the mountain. A 'shift' was 8 hours' work, thus apportioning the 24 hours into three days. About half of each shift, sometimes more, sometimes less, was occupied in drilling; the remainder of the 8 hours being taken up in unlimbering and running back the drill-carriages, waiting on the blasting, and clearing away the rock blown out. The ten shifts here instanced were worked under favoring conditions; full pressure (60 pounds on the square inch) and no interruptions of any kind. In taking an average of several *months'* working, no inconsiderable *percentage* of time lost and expense added must always, and necessarily, be embraced; the bursting of an air-duct, the breaking of a drill, or any other untoward occurrence, of course disorganizing the shift, and so swelling the per inch cost of the work in proportion to the lesser number of inches drilled. From out of those ten shifts, I quote apart the results of the *maximum* one in point of work performed. In this particular case, the heading was 'cleared for action,' the carriages run up to the face, and pressure on at exactly 6.30 A.M. (August 17th), and at 9 A.M.—2½ hours later—carriages were run back, the gates closed, and the blaster sent in to do his part. The whole expense of serving the machine-drills, including, besides miners' and machinists' wages (one machinist), those of the foreman and the drill-carrier boys, was about $45 each shift—*i. e.*, for the service actually performed *in the heading*, and exclusive of what was going on outside in the compressing of air, repairing machinery, etc. etc.

MEMORANDUM OF DRILLING IN HEADING WEST FROM CENTRAL SHAFT ON CERTAIN DAYS IN AUGUST, 1873.

10 SHIFTS.

Total time occupied in drilling (38 hours, 40 minutes)	2320 minutes.
Total number of holes drilled	120.
Total number of inches drilled	16,948.
Average depth of holes	11 feet, 8 inches.
Average number of Rock-drills used each shift	6.
Average number of inches drilled per minute	$7\frac{30}{100}$.
Average number of inches drilled by each drill per minute	$1\frac{22}{100}$.
In doing the above work, drill-points were changed	694 times.
Average number inches drilled by each point	24½ nearly.

In the best shift's work included in the above, the following was the work performed:

Time occupied in drilling (2 hours, 30 minutes)	150 minutes.
Number of holes drilled	12.
Number of inches drilled	1728.
Average depth of holes	12 feet.
Average number of inches drilled per minute	11½.

Number of Rock-drills used..6.
Average number inches per minute each drill........................$1\frac{21}{100}$.
Drill-points changed..61 times.
Average number inches to each point........................$28\frac{1}{3}$.

(The above holes were all full two inches in diameter.)

"Hoping that you will be able to extract some value from the 'results' here given, I am, dear sir, yours truly, W. SHANLY.

PART IV.

THE SUTRO TUNNEL.*

LOCATION AND HISTORY OF THE TUNNEL.

IN Story County, Nevada, at the foot of the steep eastern slope of the Sierra Nevada, from which it is separated by a deep depression, rises a great mountain chain, the Washoe Range.

Some of its summits, as Mount Cedar, Mount Davidson, Mount Butler, etc., reach a height of over 7800 feet above sea-level. Along the foot of this range runs the Carson River, which empties into the lake of the same name. On the eastern slope of this mountain chain, and in the vicinity of Mount Davidson, a spur branches off to the east, which is the divide between Gold Cañon and Six-mile Cañon, both of which empty their water into Carson River. In Gold Cañon, gold was discovered as early as 1849; in Six-mile Cañon, a heavy black, metallic substance was found in 1858; but there was no importance attached to it until the same substance was found in the following year in the excavations for a water-reservoir on the present claim of the Ophir Company. Here it was discovered in place as a vein, and on analysis was found to be ore containing silver glance and native gold. According to another version, silver ores were discovered in a quartz vein in Gold Cañon, near Silver City, as early as 1857.

Henry Comstock, after whom the lode is named, was one of the first to locate a claim upon it, and he was soon joined by many others. The original holders of claims, being generally men with small capital, are rarely the ones who ultimately reap large profits from the mines. This has been strikingly illustrated in the case of Comstock, who, after being reduced to extreme poverty, is reported to have shot himself in 1870, in the vicinity of Bozeman, Montana. The history of the various mines located on the Comstock lode furnishes an apt illustration of the wasteful system of mining pursued throughout our Western States and Territories, where the real object of systematic and careful mining has been lost sight of. It has not been the profit growing out of a continuous extraction and beneficiation of the minerals that caused the opening of numerous veins of the precious metals, but rather a spirit of wild speculation based on temporary and transient profit. Speculation in claims and shares was active from the very discovery of the Comstock lode; and local mining laws made by a mining community favored the extreme subdivision of mining claims.

Mount Davidson consists, according to Von Richthofen, of syenite, containing orthoclase, hornblende, a little mica, and sometimes epidote, but *no quartz*. This forms the foot-wall or west country-rock of the vein. Overlying the vein are what Von Richthofen has called propylites or feldspar and hornblende porphyries. These porphyries, together with thick strata of breccia and some dykes of andesite, trachyte, etc., occupy a large portion of the eastern slope of the mountain. The general strike of the Comstock lode is north and south, and its

* All the additional matter inserted in the revised description of Sutro Tunnel, and published in this second edition, has been kindly contributed by Mr. George J. Specht, Engineer Sutro Tunnel.

dip is 45° E. Both vary considerably in short distances, the vein being frequently split by large "horses" of the country rock occurring in it. The changes in dip are much more various than those in the strike, and occur oftener toward the hanging than near the foot-wall, and show everywhere that they are caused by the falling into the fissure of larger or smaller pieces of the hanging country rock. The foot-wall varies very little from the general dip, being inclined 38° to 40° near the surface, and 45° at greater depths. The width of the Comstock lode has also undergone many changes on account of the "horses" occurring in it. Near the croppings, it is reported in some places to be from 600 to 1000 feet thick, containing "horses" ranging up to 1000 feet in length by 50 to 100 in thickness, while at a depth of from 400 to 600 feet it still shows a thickness of from 100 to 130 feet. At a still greater depth, where the vein is less broken and disturbed, its width becomes less and more uniform, but is still from 30 to 60 feet.

The extraordinarily high mining expenses in this Comstock lode cannot surprise any one when we consider that there are over forty companies, each having its own superintendent and president, directors and secretaries; and the large numbers of shafts, tunnels, levels, engines, pumps, etc., of each company. This want of a concerted national mining industry on the Comstock from the commencement is to be deeply deplored. The natural way of exploring and opening the lode in depth, though it takes a tunnel of considerable length, should have been commenced while the rich upper ore bodies were being extracted, instead of having been left to a later period, when poorer ores have to be mined at a greater cost. Already before 1865, the time of the greatest production of the Comstock, the opinion became prevalent among those interested that it would be advantageous, and in a few years even imperatively necessary, for the continuance of mining, to tap the lode at greater depth by a tunnel.

Under the present system of operating the mines, the ore and refuse rock are raised to the surface through the shafts by steam-power, the ore being transported to the mills by wagons or railroad, and the refuse rock deposited in dumps contiguous to the shafts. In operating the mines by the tunnel, transportation beyond its mouth will not be necessary, as the establishment of mills for the reduction of ores at the mouth of the tunnel is an important and indeed inseparable adjunct of the tunnel project. In order that the ore should be separated cheaply and successfully, a sufficient water-power is necessary. Water to some extent may be counted upon from the drainage through the tunnel, and this will probably supply a quantity sufficient for purposes other than motive power. Should more water be required, it must be brought from the Carson River.

This stream, which has its sources in the Sierra Nevada Mountains, and is fed almost entirely from the melting snow, is not at all times to be depended upon for a supply of water. In carrying out fully that part of the project which requires the establishment of mills at the mouth of the tunnel, it will, therefore, be necessary to secure by artificial aid an adequate supply of water for running them at all seasons of the year. This it is believed may be accomplished by the construction of a high dam across a narrow gorge of the Carson River, some five miles above the mouth of the tunnel, which, by damming back its waters, shall form a lake or reservoir that will afford a supply during all seasons for operating all the mills required for the reduction of the ore which can be taken from the Comstock and from the other lodes which may be intersected by the tunnel.

The loss of precious metals by the German and English methods is represented to be exceeding 5 per cent, while in Nevada it is not far from 35 per cent in milling, with a saving of perhaps 10 per cent more in subsequent workings of the tailings and slimes, making less than 75 per cent in all. The actual loss in reduction, therefore, appears to be more than 25 per cent, which, for a production of $15,000,000 per annum, entails a loss of the precious

metals exceeding five millions of dollars, or a loss beyond what would result from the methods referred to, by which 95 per cent is saved, of at least four millions of dollars annually.

Under the present imperfect methods of mining and reduction which prevail in Nevada, ore milling less than $20, or assaying less than $30, cannot be mined with profit. Economy must, therefore, be sought for before the immense amount of low-grade ores can be profitably worked; and this economy is to be found in a more rational method of mining and in improved methods of reducing the ore; in the general application of water-power, and in the more general substitution of machinery for manual labor.

In the spring of 1860, Mr. Adolph Sutro conceived the plan of driving a deep tunnel to the Comstock lode. The undertaking, however, was of so gigantic a nature, and received so little encouragement, that active steps were not taken in the matter until the fall of 1864. On the 4th of February, 1865, the Legislature of Nevada granted a franchise which gave the right of way. The larger part of the mining companies then working upon the Comstock lode, representing 95 per cent of its value, agreed to pay a toll of $2 per ton on every ton of pay-ore taken out after the tunnel should be completed and after it should benefit each respective mine; and contracts were entered into, upon certain conditions which it has been since claimed were not fulfilled, making this a lien upon the mines for all future time. After the contracts had been made, it was considered necessary, as a security to capitalists, that the United States Government should pass a law embodying the general features of the act of the Nevada Legislature, and also of these contracts; for at that time the companies working the mines on the Comstock lode held them by possession only, the title or fee being in the United States. In consequence, an act was passed by Congress on July 25th, 1866, now commonly known as the "Sutro Tunnel Act," which gave to Adolph Sutro, his heirs and assigns, the following rights: 1. The right of way to run a tunnel seven miles in length to the Comstock lode, and a north and south drift on this vein and all others which should be found on the line of the tunnel; also the right to sink the necessary shafts on the line of the tunnel. 2. The right to purchase as much of the public land as should be necessary for the proper working of the tunnel at $1.25 per acre; the extent of the purchase not to exceed two sections (640 acres), which should not be salable as mining lands to other parties. 3. The right of acquiring at $5 per acre all veins which occur inside of a distance of 2000 feet from the tunnel on each side, excepting, however, all claims which at the time of the issue of this grant had been taken possession of by other parties, on the Comstock or any other vein. 4. To levy from all persons, companies, and corporations, who own a claim or a mine on the Comstock or any other vein opened by the tunnel, the royalty which has already been granted to the tunnel-owner by the principal mining companies on the Comstock, or which may be granted to him by other mine-owners in consideration of the drainage and other advantages accruing to the mines from the tunnels or drifts connected therewith: this last condition to be named hereafter in all the mining grants to which it may be applicable and which may be accorded by the United States. The mining companies or individual miners are not required to make any payments to the tunnel company as royalty or otherwise until the tunnel shall have been constructed and they begin to derive advantage therefrom; for an article of the law reads: "No payment shall be due or made until the works of the party of the first part shall have either actually drained said mine, so as to obviate the necessity for all other modes of drainage, or which shall be deemed and considered sufficient drainage within the meaning of this agreement."

What the future of the Sutro Tunnel Company may be is outlined by the following review of the production of the Comstock lode up to 1878 (these figures are supplied by Dr. R. W. Raymond, United States Commissioner of Mining Statistics, and from John A. Church's work, "The Comstock Lode," John Wiley & Sons, N. Y.):

PRODUCT OF THE COMSTOCK LODE.

Years.	Coin Value.	Years.	Coin Value.
1860	$1,000,000	1870	$8,319,698
1861	2,275,256	1871	11,053,328
1862	6,247,047	1872	13,569,724
1863	12,486,238	1873	21,534,727
1864	15,795,585	1874	22,400,783
1865	15,184,877	1875	26,023,036
1866	14,167,071	1876	38,572,984
1867	13,738,618	1877	33,891,698
1868	8,499,769	1878	19,051,980
1869	7,528,607		

Total gold and silver product for nineteen years....................$291,341,026

The gold product was, according to Mr. J. D. Hague's computation, based upon calculations of the varying proportion of gold in the Comstock bullion at different periods, about 40 per cent. of the whole.

We may therefore state the product of the Comstock lode, for the period named, to have been, in round numbers, say $300,000,000.

Mr. Sutro's scheme was to make the tunnel proper a main artery as it were, from which branches, now building, will extend throughout the entire mining district, which has a width of some 8000 feet and a length of from 5 to 7 miles. This it is proposed to cross-cut at intervals of from say 500 to 1000 feet, and again cross-cut parallel to the tunnel at distances of from 200 to 300 feet, thus finding all bodies of ore or bonanzas existing in the district. At the same time Mr. Sutro is confident that the tunnel company can give such cheap transportation and facilities for concentration at the mouth of the tunnel as will enable the full scheme to be carried out.

The Sutro Tunnel Company is a joint-stock company, which has a capital stock of some $20,000,000, divided into two million shares, of $10 each; it was incorporated under the laws of California in 1869. Mr. Sutro himself acted as superintendent and general manager of the company, and he is a large stockholder in the concern.

The tunnel commences at the town of Sutro, which is located in the Carson valley, 3½ miles from Dayton, and 1½ miles from the Carson River. Its general course is W.N.W., with a rise of 3 inches in 100 feet. It reaches the lode at a distance of 19,899 feet from the mouth and 1970 feet below the croppings on the Savage claim (1922 feet below the shaft-mouth of that mine). Lateral tunnels have been driven along the lode both north and south from this point. The bill reported to the Forty-second Congress requires that the main tunnel shall, throughout its entire length, have a cross-sectional area of at least 140 square feet, including timbers and space for drainage, and shall, on or before its completion, be provided with necessary timber supports, double railroad-tracks, and working-shafts.

Work was commenced on this important enterprise on October 19, 1869, at which time but 15 men were employed, and they only on day "shifts." Operations were conducted on this limited scale up to December 1st, 1871, at which date the heading, the only point where work was prosecuted, had been driven a distance of 2601 feet. Under the impetus given by the consummation of successful financial negotiations, the force was increased during the month of December, 1871, to 232 men. When operations were commenced on this enlarged scale, the force was divided into three shifts of 8 hours each, and the work was prosecuted day and night steadily. On the 8th of April, when the tunnel was yet 700 feet from the connecting point with the Savage mine blasts, the falling of rock could be distinctly heard in the header, and on the 8th of July, 1878 connection was made with a drift from the Savage mine at a total distance of 20,018 feet, a strong draft setting in at once. The hanging wall of the Comstock lode was intersected at 19,987 feet at the south side, and 20,000 feet at the north of the tunnel.

On September 1st, 1878, at a total distance of 20,489 feet the work was discontinued, and on the following day the South Lateral Tunnel was commenced at a point 19,715 feet from the tunnel portal. At the same date work was begun on the subdrain intended to carry off the hot water from the mines.

On the 18th of October, 1878, a drift from the combination shaft connected with the tunnel at a point 18,680′. The Julia shaft connected with the South Lateral on February 15th, 1879. On the following morning the continuation of the South Lateral toward the Yellow Jack shaft was commenced at a point 70′ north of the Julia connection, but on February 17th, 1879, the entire works were stopped pending negotiations with the Comstock mines.

The work on the subdrain was started up again on May 1st, 1879, with a force of 1000 men, and on June 30th, 1879, the pumps were started at the Savage, Hale and Norcross and Combination Shaft. In one hour and twenty minutes the hot water reached the mouth of the tunnel, showing a temperature at first of 101°, which gradually increased to 118°. At 19,200 feet a station for the North Lateral branch was commenced on July 1st, 1879, the cross section of both laterals being 90 square feet each.

Work was vigorously pushed so that the Mint Shaft secured a connection with the tunnel on the 14th of October, 1879, and the Bonner and Orbiston, the C. & C., and the Ophir Shaft workings on the Comstock Lode were reached respectively on the 8th of January, the 28th of April, and the 25th of August, 1880. At the present time (1881) the South Lateral Tunnel is the only one being worked, the North Lateral having been stopped on the 4th of October, 1880, in accordance with an agreement made with the mines interested.

During the process of construction of the main tunnel four shafts were located along the line, and hoisting-engines and pumps purchased for each. The following table gives their location and depth to grade:

TABLE 35.

Number of Shaft	Distance from Mouth of Tunnel.	Depth to Grade.
Shaft No. 1 reached bottom	4,915	523
" 2 " "	9,065	1,041
" 3 abandoned when 456 feet down	13,545	1,361
" 4 " " 674 " "	17,695	1,485

There was also an air shaft 5 by 4 feet in the clear, located 2250 feet from the mouth of

the tunnel. It was constructed and used for the purpose of supplying fresh air to the workmen, and for hoisting out rock and *débris* while the heading between the mouth and Shaft No. 1 was being driven.

The pumps used in the shafts were double-acting cataract steam-pumps, manufactured by Messrs. Allison & Bannan, of Pottsville, Pa. Steam cylinders 20" by 72", and 10" discharge-pipes, weighing 20,000 lbs. each, and capable of lifting the water from station to station 300 feet apart. Steam-pumps of this capacity had not previously been introduced on the Pacific coast, though they had been in use quite extensively in the coal regions of Pennsylvania. They proved greatly preferable to the old style of Cornish pumps, as being simpler in construction, cheaper to work, more durable, and less liable to get out of order. In April, 1872, the superintendent of machinery reported that over 3,000,000 gallons of water had been pumped from No. 1 shaft during the month. Great quantities of water were in fact met in all these shafts, and Nos. 3 and 4 ultimately had to be abandoned on account of the great influx of water, which could not be overcome.

After the tunnel passed the foot of Shaft No. 2, it was found that a strong draught set in from the mouth and passed up the shaft. Beyond the shaft, artificial ventilation has been found necessary, two No. 4 Root's blowers being used, with 11-inch galvanized iron tubing.

Some of the ground met in driving the tunnel was found to be very heavy. In one place, the pressure was so great as to break timbers 12 by 14 inches, crushing the posts into the caps, and often snapping the posts. In this ground, the size of the timber was increased to 14 by 16 inches, and instead of placing the bents 5 feet apart from centre to centre as usual, they were here put close against each other. Some of the falls in the very bad material extended as high as 18 feet above the timbers. At these points the cavities had all to be blocked up.

Work in the South Lateral of the Sutro Tunnel now (1881) progressing represents one of the most difficult problems of tunneling, as the ground for almost its entire length swells in a very serious manner. Timbers of 14" by 16" have been crushed after they were in but two days; they require constant easing up, which is considered the only efficient means of keeping the tunnel open, and which is continued until the swelling ceases. Much of the ground passed through consisted of hard and very hard porphyry and andesite bowlders imbedded in clay, the character being such as to offer two great obstructions to progress; hard drilling and very heavy timbering, requiring false sets and lagging ahead. Another disadvantage in the work at the South Lateral was the difficulty of procuring sufficient ventilation, both water and rock showing a high temperature.

The timber used is sawed pine, and in bad ground the centre-piece of a tree is always selected. Timber costs, on an average, $30 per M. delivered at the mouth of the tunnel. Wood is used for fuel, costing $6.50 per cord delivered.

When timbered, the tunnel, as far as completed, is 12 by 16 feet outside of the timbers, which are 10 by 12 inches, except the inside posts, which are 10 inches square. This is divided into two compartments, each 5½ feet wide at the bottom, 4½ at the top, and 10 feet high, with a passageway between and a drain underneath. The top and sides are covered with lagging of two-inch plank. Like the mines of the Comstock lode, ventilation proved a difficult problem, and Mr. Specht adds to the testimony given by Prof. John A. Church the following practical observations of recent date:

The lateral branches or headings are ventilated by 2 Root blowers, No. 4, and 1 Baker blower, No. 5, which are situated in a drift connecting the tunnel with the Mint Shaft. This is a downcast, and furnishes a large amount of fresh air of from 47° to 60° (winter or summer). The station is 1,361' below the surface. The air is conveyed from the blowers to the

working places by pipes of galvanized iron of 11″ diameter, which are gradually replaced by 15″ pipes. The respective distances from the blower station to the headings are 3,735′ (North Lateral, October 1, 1880), and 4,900′ (South Lateral, December 22, 1880).

The air, when entering the blower pipe, has a temperature of 60° (September 30), and when issued at the face 104°.

This shows that the air takes up a great deal of heat on its way, which is partly due to the friction in the pipes, partly to the influence of the air surrounding the pipes. The temperature in the header is mostly a few degrees lower than or about the same as the temperature of the air from the blower pipe. Therefore, the blower pipe supplies *hot* air, which benefits not by its temperature, but by its purity and freedom of carbonic acid, while the air in the face is not any longer fit to be inhaled. The air from the blower pipe feels to the men much cooler than the air in the face, and is eagerly sought for, but it does not cool the air directly. The effect of the cold produced by the blower air has several reasons.

The vitiated air must be substituted by a sufficient supply of fresh, *dry* air, which is capable to quickly remove or vaporize the perspiration from the body of the men. If this is retarded there is a sense of suffocation, and this may take place either with deficient ventilation, or even in a fair current of air. The air supplied should have a high capacity of absorbing moisture.

The air forced by the blower into the pipe is compressed to a certain degree, and when issuing from the pipe it expands, and thereby creates cold; the temperature one foot inside of the pipe was 100° (December 22), and two feet in front of the pipe it was 98°. The air-current leaves the pipe with comparatively great velocity (1200′–1700′ per minute, furnishing from 1100 to 1600 cubic feet per minute), and is almost dry; meeting the wet bodies of men and animals, it eagerly absorbs the humidity, which evaporates, and thereby dries and cools the skin.

The air streaming from the blower pipe forms a cone; a person standing within this cone feels refreshed and cooled, but standing only one inch outside of it, he does not derive any benefit of it. The benefit of this fresh air-current is limited only to the face and a short distance below it. The longest part of the drift is not directly or not at all benefited by it.

It may not be out of place to quote Prof. John A. Church, who says, on page 20 of his report on the Comstock Lode: "This (the requirement of *dry* air) was constantly proved by leaving thermometers with the men, who would not, without experimental proof, believe that the places which they sought for cooling off were sometimes hotter than those where they worked, and frequently had precisely the same temperature. It is true that an increase of a few degrees in the temperature of a drift will sometimes bring with it an exhaustion which is out of proportion to the heat change alone. This is explainable on the supposition that the increased heat is due to an unusual access of gas, and such places frequently become more comfortable after a few days."

The great desideratum of artificial ventilation is *dry* air. The two Root blowers are run by a compressed air engine, connected with the latter by belts; the Baker blower is run by an Armstrong water-engine with oscillating cylinders. The Root blowers make usually 110–120 revolutions per minute, and the Baker blower 55–60.

The Main Tunnel is ventilated by natural draft entering at the mouth and escaping through the Savage Shaft. Until lately shaft No. 2 was used, and, being an upcast, created a strong draft from the tunnel mouth to there, but the part of the tunnel above No. 2 derived very little profit thereby. At that time from 36,000 to 40,000 cubic feet of fresh air per minute entered the tunnel through its mouth and Shaft No. 1; Shaft No. 2 took 20,000–25,000 cubic feet thereof, permitting only 14–15,000 cubic feet of fresh air to flow along the

upper portion of the tunnel. Since No. 2 is abandoned the station at the bottom of it is tightly closed off, and now there are only 27,000 cubic feet entering the tunnel, but the whole amount of fresh air traverses the entire length of the tunnel, thereby lowering the temperature above No. 2 one or two degrees. This corroborates the statement of Mr. J. N. Rastrick (see p. 1039 of the author's work on "Tunneling"), that shafts in a long tunnel having openings at each end are rather an impediment than a benefit to the ventilation. The Sutro Tunnel presents, as far as the Main Tunnel is concerned, a perfect parallel case to a long tunnel of a narrow-gauge railroad, and therefore fits exactly to the above quotation.

Since lately the compressed air is not made any more at Shaft No. 2, but at the Bonner Shaft of the Gould & Curry Mine by a large Rand compressor. The pressure ranges from 70 to 90 lbs. per square inch, and the compressor works to full satisfaction.

Introduction of Machine Drills.

In September, 1872, the first attempt at machine-drilling was made. Several diamond drills arrived from the East, and one was put in operation, giving the following results: 542 feet of holes were drilled in thirty days, including the time occupied in moving the machine and the large girder it rested on. This drilling was done in a side-hill embankment at the tunnel-entrance. The nature of the ground varied considerably, consisting chiefly of conglomerate, cement-gravel, and trachyte, and it was found far more difficult to drill than if it had all been hard rock, in consequence of the drill being subjected to uneven strain by one side of it coming in contact with, perhaps, a piece of agate, while the other side would be conglomerate. But the chief disadvantage in drilling in this comparatively loose and seamy earth was, that the holes became so uneven by pieces of rock, etc., falling around the sides of the drill and making the holes irregular in shape, causing the bits to catch when they were withdrawn. The bits used were of brass, 1¾" diameter, and containing 20 diamonds each. The deepest hole drilled was 22½ feet, and the average depth of the holes 10 feet. Subsequently the Burleigh drill was introduced in 1874. These drills were at first supplied with air by a compressor located at Shaft No. 1, constructed by the Société John Cockerill, of Seraing, Belgium. After Shaft No. 2 had been passed, the compressor at Shaft No. 1 was exchanged for a new one started at Shaft No. 2. This latter one was built by the Humboldt Company, of Kalk, near Deutz, one the Rhine. Both of these compressors, Mr. Sutro reports, have given great satisfaction. (For cuts and descriptions of them, see Chapter V., p. 155, etc.) There has also been a small auxiliary Burleigh compressor in occasional use.

When machine-drills were first introduced into the tunnel in 1874, the Burleigh drill was adopted. From the experience at Hoosac and Mont Cenis, Mr. Sutro supposed that perhaps a proportion of some five drills would be needed for every one in operation; but practical experience has shown here that for the six drills in use, four, or six at most, additional ones would keep the heading going without any interruption, provided there be a machine-shop and proper mechanics employed to keep the machines in repair. This accords with the experience at Musconetcong Tunnel, where an average of 26 drills was found sufficient to keep some 16 to 18 going. English steel was at first used at Sutro, but subsequently Pittsburg Black Diamond steel was substituted, and found to be fully equal to the English. The heading was driven 8 feet by 10 feet wide, and this cross-section was ultimately enlarged to 10 by 12 feet in the clear. The centre-cut and squaring-up system of blasting (described under Musconetcong) was used. The cut generally had a depth of from 7 to 8 feet and a face of from 4 to 5 feet. The rate of advance, as will be seen by consulting the progress table, p. 375, has been vastly accelerated by the introduction of machine-drilling and high explosives. (Dynamite was introduced into the tunnel about 1870.)

Prices of Labor.

All work on the tunnel has been done by day labor, with the exception of some small contracts in the very first stages of the work. The rates of pay have been as follows (8-hour shifts):

Foremen per day	$8 00
Shift bosses	6 00
Drill-men and blasters	5 00
Laborers, car-men, and all others employed under ground	4 00
Outside laborers	3 00

In addition to the above rates, the following premium was offered in May and June, 1875:

For every foot of lineal progress over 300 feet per month, and under 400	$5 00	per foot.
For every foot of lineal progress over 400 feet per month, and under 500	10 00	"
Anything over 500	20 00	"

This was divided equally among all the men employed under ground.

In the heading, there were two men to each one of the six machines, or one drill-man and one miner assisting, making a total of 36 men per day of three shifts. These 12 men to a shift did all the work of shoveling and clearing in the heading, in addition to the drilling.

Mr. Specht has furnished the following recent data on the cost of drifting:

Cost of Drifting.

One lineal foot of South Lateral cost:

1. Average of 14 weeks from September, 1878, to February, 1879, 4 six-hour shifts; only the direct cost of advancing the heading, *not* including timbers, track, general management, and other outside expenses:

One lineal foot required—

Shift boss	0.40	@ $6 00	=	$2 40	Ground medium, porphyry; cross-section 90 square feet.
Miners	3.58	@ 4 00	=	14 32	
Blasters	0.40	@ 5 00	=	2 00	
Car-men	0.95	@ 4 50	=	4 27	
Track-layers	0.43	@ 4 00	=	1 72	
Lbs. of powder	9.30	@ 0 35	=	3 25	
No. of electric exploders	3.05	@ 0 075	=	0 23	
Drills sharpened	6.70	@ 0 20	=	1 34	
Cans of castor oil	0.0573	@ 6 50	=	0 37	
" " lard "	0.129	@ 4 00	=	0 52	
" " coal "	0.0204	@ 2 13	=	0 43	
Boxes of candles	0.0798	@ 6 00	=	0 48	
				$31 33	

The cost of compressed air per one foot tunnel during the same period was:

0.110 boss engineer,	0.11 station tender,	Amounting to $17 20 per foot. South Lateral only running.
0.225 engineer,	0.11 car-men,	
0.332 firemen,	1.68 cords of wood,	
0.178 laborers,		

2. Average of 3 weeks, October, 1880—3 eight-hour shifts:

0.296	bosses	$1.776
3.113	miners	12.452
0.292	blasters	1.460
0.398	car-men	1.790
0.0985	track-layer	0.394
0.1971	engineers (ventilation)	0.985
6.952	powder	2.433
2.967	exploders	0.223
3.541	drills (at 24 cents)	0.860
	Oil and candles same as above	1.800
		$24.173

Cost of compressed air during same period per one foot tunnel:

0.0985	boss engineer	$0.591	South Lateral only running.
0.1971	engineers	0.986	
0.2957	firemen	1.183	
0.0985	laborers	0.345	
0.0985	station tender	0.394	
0.0985	car-men	0.394	
1.149	cords of wood	10.341	
		$14.234	

3. Cost of one foot South Lateral during the week from May 22d to May 31st, 1880, when a progress of 148 feet was made (the largest progress of one week ever made in the Sutro Tunnel).

0.203	shift boss	$1.218
2.02	miners	0.080
0.203	blasters	1.015
0.370	car-men	1.665
0.067	track-layer	0.268
0.067	engineers (ventilation)	0.335
7.760	lbs. of powder	2.716
2.81	exploders	0.211
2.715	drills (at 22 cents)	0.597
	Oil and candles same as above	1.800
		$17.905

The cost of compressed air during that period, when both headers were running, amounted to $7.635 (average of 25 weeks).

Drilling and Blasting at Sutro.

With regard to the details of the machine-work at Sutro in good rock, Mr. Sutro gives* the average number of inches of drilling per cubic yard of rock broken as 97. Explosive used exclusively is giant and hercules powder, No. 1 and No. 2, and vulcan powder, No. 2.

The "attacks," or drilling heats, vary, of course, with the character of the rock, the maximum being 2 drilling heats in 4 shifts, of 8 hours each.

Six drills were used in the face until March 1st, 1877, and now (1881) the company has sixteen 5-inch and four 3½-inch drills, sufficient to keep 10 to 12 machines steadily at work. Ingersoll drills have done the work. The wages have continued throughout the work at the rate given above. Mr. Sutro gives his general estimate of hand and machine labor as follows: "My general opinion is, that in a large heading, say like the one we are driving (8 by 10 feet), the cost of machine labor is 33 per cent less than what it would be by hand labor, and the progress triple. In a small heading, say 5 feet wide and 6 feet high, I should consider the cost by machine labor about equal, if not larger than by hand labor, and the progress by the former hardly double that of the latter. The reason why a large heading can be driven cheaper and faster is, that we can drill 8 and 10-foot holes for the cut; while in the smaller tunnel it is difficult to drill them over 4 or 5 feet, since there is not sufficient room to place the machines at the proper angle for drilling the deep holes which are intended for blasting out the cut." (By consulting the description of the St. Gothard Tunnel [p. 359], and the tables [p. 382], it will be seen that their holes abroad do not average in the heading one metre in depth, and they are purposely set normal to the face, the face of the heading being literally "sieved" with holes, and charged with dynamite.)

Recent experience at the Sutro Tunnel with machine drills is summed up by Mr. Geo. J. Specht, C.E., as follows: The parts mostly exposed to breakage and the quickest worn out are the riffle-bar, tappets, pawls and cylinder-heads. Unfortunately, no record has been kept of the number of machines repaired and the cost of repair until recently. It is estimated, however, that the cost of labor for repairs does not exceed $200.00 per month, that is, when about 8 machines are running. The 3½" machines are of the latest so-called "Eclipse" pattern, without tappets. The experience with the latter at the Sutro Tunnel is that the valve easily gets stuck and cannot be made to work again by the common miner; the tappets are preferred if the machine is in the hands of a non-mechanic. The following is a statement of how many feet of holes (2½") were drilled in one hour in different kinds of rock and by the different machines. These data are obtained from actual work, and not from trials:

* Letter to author dated July 28, 1877.

	In very hard Andesite and Porphyry.		In hard Andesite and Porphyry.		In medium Porphyry.		In soft Vein Porphyry, vein matter	
Six Burleigh drills made in 1 hour:								
Average	22.96′	Out of 9 observations.	32.10′	Out of 61 observations.	36.59′	Out of 40 observations.	41.55′	Out of 41 observations.
Maximum	36.00′		69.50′		66.50′		120.00′	
Minimum	12.70′		17.50′		20.00′		22.50′	
Four Ingersoll drills made in 1 hour:								
Average	17.47′	Out of 8 observations.	21.50′	Out of 7 observations.	39.73′	Out of 40 observations.	53.90′	Out of 21 observations.
Maximum	25.20′		32.7′		74.80′		85.30′	
Minimum	10.5′		14.00′		14.00′		27.00′	

This time includes all delays during the drilling.

The four drills are fixed upon one large, heavy drill-carriage.

The following tables, prepared by Mr. Geo. J. Specht, C.E., Sutro Tunnel Co., give the details of the most recent work in the North Lateral Tunnel, work on which was stopped on the 4th of October, 1880. No details of the work on the South Lateral are given, as the nature of the ground makes it exceptional. (See also Tables, pp. 376 and 377.)

TABLE OF WEEKLY PROGRESS OF THE NORTH LATERAL SUTRO TUNNEL.

Week ending	No. of work-days.	Progress per week.		Holes Drilled.			Powder Consumed, lbs.	No. of Exploders Used.	No. of Carloads of Rock Removed.	No. of Drills Sharpened.	Character of Rock.	Average Progress per 24 hours.		One Lineal Foot of Drift Required				One Cubic Yard of Rock Required			
		In Feet.	In Cubic Yards.	Number.	Average Depth.	Aggregate Depth.						Feet.	Cubic Yards.	Feet of Drill-holes.	Lbs. of Powder.	No. of Exploders.	No. of drills Sharpened.	Feet of Drill-holes.	Lbs. of Powder.	No. of Exploders.	No. of drills Sharpened.
1879.																					
August 8.	7	53	177	126	4.7	598	222	125	245	176	Porphyry, hard.	7.58	25.3	11.29	4.19	2.30	3.32	3.38	1.25	0.71	0.99
August 15	7	48	160	134	7	938	454	139	219	56[illegible]	Andesite, very hard, took 18–22 hours to drill a round of holes.	6.86	22.9	9.55	9.38	2.90	11.70	5.86	2.84	0.87	3.52
August 22	6	61	203	175	7.6	1340	479	184	263	385	11′ Andesite, 50′ Vein Porphyry, good.	10.30	33.9	22.00	7.85	3.02	6.31	6.51	2.36	0.91	1.89
Sept. 1...	10	105	350	256	8.7	2246	928	279	509	468	Porphyry, with Quartz and Clay, good.	10.5	35.0	21.40	8.84	2.66	4.46	6.42	2.66	0.80	1.34
Sept. 8...	7	66	220	155	8.3	1296	398	146	358	374	Porphyry, hard.	9.43	31.4	19.62	6.03	2.21	5.67	5.91	1.81	0.65	1.70
Sept. 15..	7	48	160	171	8.3	1271	530	170	328	394	5′ Porphyry, 43′ Andesite, very hard, last 20′ little wet.	6.86	22.9	26.50	11.01	3.54	8.21	7.95	3.31	1.06	2.46
Sept. 22..	7	47	156	146	8	1168	514	151	360	481	6′ Andesite, 26′ Vein Porphyry, 1′ Clay and decomposed Quartz, 14′ Vein Porphyry.	6.72	22.3	24.85	10.92	3.22	10.22	7.49	3.29	0.97	3.08
Oct. 1....	9	40	133	108	7.7	800	345	112	238	610	16′ Vein Porphyry, 24′ Andesite, hard.	4.45	14.8	20.00	8.64	2.80	15.26	6.01	2.59	0.84	4.59
Oct. 8....	7	58	194	174	7.3	1206	483	177	269	524	37′ Andesite, 21′ Porphyry, very hard.	8.29	27.7	20.82	8.35	3.05	9.05	6.32	2.49	0.91	2.70
Oct. 15...	7	69	230	175	7.7	1332	653	188	306	614	Porphyry, very hard.	9.86	32.9	19.32	9.49	2.73	8.91	5.80	2.84	0.82	2.67
Oct. 22...	7	73	243	240	7.7	1847	920	258	314	1058	Porphyry { 34′ very hard, 39′ good.	10.41	33.3	25.30	12.60	3.54	14.43	7.60	3.78	1.06	4.33

Table of Weekly Progress of the North Lateral Sutro Tunnel.—(*Continued.*)

Week ending	No. of work-days.	Progress per week. In Feet.	Progress per week. In Cubic Yards.	Holes Drilled. Number.	Holes Drilled. Average Depth.	Holes Drilled. Aggregate Depth.	Powder Consumed, lbs.	No. of Exploders Used.	No. of Carloads of Rock Removed.	No. of Drills Sharpened.	Character of Rock.	Average Progress per 24 hours. Feet.	Average Progress per 24 hours. Cubic Yard.	One Lineal Foot of Drift Required: Feet of Drill-holes.	One Lineal Foot of Drift Required: Lbs. of Powder.	One Lineal Foot of Drift Required: No. of Exploders.	One Lineal Foot of Drift Required: No. of drills Sharpened.	One Cubic Yard of Rock Required: Feet of Drill-holes.	One Cubic Yard of Rock Required: Lbs. of Powder.	One Cubic Yard of Rock Required: No. of Exploders.	One Cubic Yard of Rock Required: No. of drills Sharpened.
1879.																					
Nov. 1....	10	110	366	229	6.7	1562	375	247	595	343	Porphyry, broken up. 95′ closely timbered.	11.00	36.6	14.21	3.41	2.25	3.12	4.27	1.03	0.68	0.94
Nov. 8....	7	90	300	223	7	1561	374	212	430	276	Porphyry, broken up. 39′ closely timbered.	12.85	42.8	17.35	4.16	2.36	2.96	5.21	1.25	0.71	0.92
Nov. 15...	7	56	186	129	7.7	954	251	115	347	242	Porphyry, 56′ timbered. About 3 m. inch. of water (115°).	8.00	26.6	17.00	4.49	2.06	4.32	5.13	1.35	0.62	1.30
Nov. 22...	7	45	150	87	6.3	573	79	59	279	210	20′ Propylite, 25′ Porphyry, sliding, timbering wet.	6.43	21.5	12.76	1.76	1.32	4.67	3.83	0.53	0.39	1.40
Dec. 1....	9	110	366	226	7	1582	357	203	234	268	60′ Prophyry, 20′ timbered. 50′ Propylite.	12.23	40.7	14.40	3.25	1.85	2.44	4.33	0.98	0.56	0.73
Dec. 8....	7	94	313	212	7	1484	201	219	431	268	34′ Propylite, 60′ Porphyry, with Quartz and Clay, good.	13.42	44.7	15.81	2.14	2.33	2.85	4.74	0.64	0.70	0.86
Dec. 15...	7	109	363	194	7	1358	387	200	449	336	50′ Porphyry, 59′ Propylite.	15.65	51.9	12.46	3.55	1.83	3.08	3.72	1.06	0.55	0.93
Dec. 22...	7	76	253	170	7	1190	403	182	370	710	40′ Propylite, 24′ timbered, 36′ Andesite.	10.85	36.1	15.67	5.32	2.39	9.35	4.71	1.59	0.72	2.81
1880.																					
Jan. 1....	9	113	376	254	7.3	1848	559	257	515	723	Andesite, good.	12.57	41.8	16.33	4.95	2.27	6.40	4.91	1.49	0.68	1.93
Jan. 8....	7	83	276	113	9	1017	221	121	396	225	Propylite, good timbering.	11.85	39.4	12.26	2.66	1.46	2.71	3.68	0.80	0.44	0.82
Jan. 15...	7	139	463	262	7.3	1942	555	286	477	264	Vein Porphyry, soft, has to be timbered when passed through.	19.86	66.3	13.97	3.99	2.06	1.90	4.19	1.19	0.62	0.57
Jan. 22...	7	104	346	270	7.4	1996	533	276	500	273	Vein Porphyry, 40′ timbering.	14.86	49.5	19.40	5.14	2.66	2.63	5.77	1.54	0.80	0.79
Feb. 1....	10	103	343	299	7.3	2222	985	397	608	558	Vein matter, good, 20′ timbered.	10.30	34.3	21.60	9.56	3.85	5.41	6.50	2.87	1.16	1.63
Feb. 8....	7	84	280	228	7.5	1731	740	235	367	253	Vein Porphyry, 54′ good, 30′ soft, timbered.	12.00	40.0	20.61	8.82	2.80	3.02	6.19	2.64	0.84	0.91
Feb. 15...	7	72	239	218	6.7	1746	839	289	343	321	1 m. inch of water. Vein Porphyry, good.	10.28	34.2	24.28	11.64	4.02	4.46	7.32	3.51	1.21	1.34
Feb. 22...	7	72	239	249	8	1992	1096	336	395	351	Vein Porphyry, good. 3 inch. of water (109°).	10.28	34.2	27.70	15.25	4.67	4.87	8.35	4.59	1.41	1.47
March 1..	9	80	266	201	7.6	1518	451	190	436	460	Vein Propylite, good, 80′ timb. wet.	8.89	29.6	18.95	5.64	2.38	5.75	5.71	1.69	0.71	1.73
March 8..	7	77	256	144	8	1152	353	159	432	455	Vein Propylite, good, 77′ timb.	11.00	31.6	14.96	4.58	2.06	5.91	4.51	1.38	0.62	1.78
March 15.	7	73	243	150	7.8	1174	359	170	418	495	Vein Propylite, good, 43′ timb.	10.43	34.7	16.10	4.92	2.33	6.79	4.83	1.47	0.70	2.04
March 22.	7	65	216	82	8	656	266	106	454	677	Vein Propylite, hard, 50′ timb.	9.29	30.8	10.09	4.10	1.63	10.40	3.04	1.26	0.49	3.14
April 1...	10	68	226	201	8	1608	547	210	488	841	Vein Propylite, hard, 53′ timb.	6.80	22.6	23.65	8.05	3.09	12.37	7.12	2.42	0.93	3.72
April 8...	7	67	223	230	8	1860	1027	288	333	905	Vein Propylite & Porphyry, very hard (37′), hard (30′).	9.58	31.9	27.80	15.32	4.30	13.49	8.35	4.61	1.29	4.06
April 15..	7	63	210	152	8	1216	392	171	378	860	40′ Porphyry, good, timber 23′ Propylite, hard.	9.00	30.0	19.32	6.22	2.72	13.65	5.78	1.87	0.82	4.10
April 22..	7	82	273	173	8	1384	521	216	501	415	15′ Propylite, hard, 67′ Porphyry, good, 49′ timb.	11.72	39.0	16.90	6.35	2.63	5.06	5.07	1.91	0.79	1.52
May 1....	9	79	263	148	7.6	980	215	150	520	483	Vein Porphyry.	8.79	29.2	12.40	2.72	1.90	6.12	3.72	0.82	0.57	1.83
May 8....	7	69	230	156	8	1319	301	152	442	286	Vein Porphyry, timb. 69′.	9.86	32.8	19.12	4.36	2.21	4.15	5.74	1.31	0.66	1.24
May 15...	7	80	266	187	8	1496	427	220	507	316	Vein Porphyry, timb. 80′.	11.43	38.0	18.70	5.34	2.75	5.95	5.63	1.61	0.83	1.89
May 22...	7	66	220	171	8	1368	413	208	447	366	Propylite, timb. 66′.	9.43	31.4	20.70	6.27	3.15	5.55	6.22	1.88	0.95	1.66
June 1...	10	106	353	245	8	1960	569	259	615	656	Propylite, 86′ timb.	10.60	35.3	18.50	5.37	2.44	6.19	5.56	1.61	0.73	1.86
June 8...	7	100	333	333	8	2664	1261	397	496	450	40′ Propylite, hard, 60′ Porphyry, Clay, good.	14.29	47.6	26.64	12.61	3.97	4.50	8.01	3.79	1.91	1.35
June 15..	7	102	340	324	8	2592	951	302	471	343	Porphyry, Quartz, good.	14.58	48.6	25.39	9.32	2.96	3.36	7.62	2.80	0.89	1.01
June 22..	7	84	280	231	8	1884	754	245	451	368	Porphyry, Quartz and Clay, good, 50′ timbered.	12.00	40.0	22.40	8.97	2.92	4.38	6.73	2.69	0.88	1.32
July 1....	9	118	393	334	8	2672	1197	338	507	732	Porphyry, Clay, good, 10′ timbered.	12.00	43.7	22.65	10.15	2.87	6.21	6.79	3.04	0.86	1.86
July 8....	6	72	240	205	8	1640	751	230	323	459	Porphyry, Clay and Quartz, hard.	12.00	40.0	22.80	10.41	3.19	6.38	6.85	3.13	0.96	1.91
July 15...	7	57	189	210	8	1680	803	219	312	1111	Same.	8.14	30.0	29.50	14.09	3.84	19.50	8.89	4.25	1.16	5.88
July 22...	7	78	260	233	8	1864	988	250	395	609	Same.	11.14	37.2	23.90	12.67	3.21	7.81	7.16	3.81	0.96	2.34
August 1.	10	97	323	280	8	2240	706	290	499	926	Same, 27′ timb.	9.70	32.3	23.10	7.28	2.99	9.55	6.95	2.19	0.89	2.87
August 8.	7	*44	163	150	8	1200	379	214	395	425	Same, very hard, timb.	6.29	23.3	27.30	8.61	4.86	9.66	7.39	2.32	1.31	2.61
August 15	7	*46	170	144	7.7	1116	561	219	300	580	Same, very hard, 17′ timb.	6.57	24.3	24.30	12.39	4.76	12.60	6.56	3.30	1.29	3.41
August 22	7	*72	266	222	7.8	1732	778	249	403	607	Same, good.	10.28	38.0	24.10	10.60	3.46	8.44	6.52	2.93	0.94	2.27
Sept. 1...	10	*81	300	261	7.5	1957	777	258	464	502	Same, hard.	8.10	30.0	24.10	9.61	3.18	6.21	6.52	2.59	0.86	1.67
Sept. 8...	7	58	193	216	8	1728	884	262	333	591	Propylite, hard.	8.29	27.6	29.80	15.22	4.52	10.19	8.95	1.52	1.36	3.06
Sept. 15..	7	62	206	185	7.5	1388	675	196	297	528	Same.	8.86	29.4	22.40	10.87	3.16	8.53	6.74	3.28	0.95	2.57
Sept. 22..	7	61	203	179	8	1432	393	182	335	205	Vein matter, good.	8.72	20.9	23.5	6.45	2.98	3.36	7.06	1.93	0.89	1.01
Oct. 4....	13	122	407	401	7.88	3160	1524	475	641	711	Same, hard.	9.39	31.3	25.9	12.49	3.89	5.83	7.78	3.72	1.17	1.75

For further information on the Sutro Tunnel, see Richthofen's "Metall-Production Californiens," in Petermann's "Geographischen Mittheilungen," Supp. No. 14, 1864. Also, Richthofen's "The Comstock Lode, its Character, etc.," San Francisco, 1866; and an extract from it by Von Cotta in the "Berg und Hüttenmännische Zeitung," 1867, p. 413.

Also, see "Reports upon the Mineral Resources of the United States," by J. Ross Browne and James W. Taylor, 1867, and "Report of J. Ross Browne on the Mineral Resources of the United States and Territories West of the Rocky Mountains," 1868.

Also, R. W. Raymond's Reports from 1869 to 1876, inclusive, on "Mineral Resources West of the Rocky Mountains."

Also, "The Sutro Tunnel," by Adolph Sutro, Baltimore, John Murphy & Sons, 1868; and the various reports and hearings on the Sutro Tunnel before the Congressional Committees, 1872.

Also, "The Comstock Lode, its Formation and its History," by John A. Church, New York; John Wiley & Sons, 1879.

The Sutro Tunnel and the Rothschönberger Stollen contrasted.

The following summary* of progress at the Rothschönberger Stollen, in Saxony, will give some idea of the importance attached to the construction of deep mining adits abroad. This tunnel was commenced in 1844, and formally opened April 12th, 1877; all but the last few hundred metres were driven by hand labor. The later returns of machine-work have not been received; but it is understood that the best average attained was 85 metres per month, or 279 feet.

The whole length of the adit, as finally run, was 13,901 metres, starting from the Triebisch Valley at Rothschönberg, above Meissen, on the Elbe. The distance to Halsbrucke on the original location was 12,882 metres (42,266 feet), and the depth reached below the Anna Stollen, the deepest previously existing, 94 metres (308 feet). At the time of the final connection with Himmelfahrt, the tunnel and its branches together comprised a continuous completed length of nearly 29,000 metres (95,149 feet). Additional branches are also projected, which will eventually make a complete length for the adit and branches of some 50,900 metres (166,003 feet), or 31·6 English miles. This will be the longest adit in the world. The total cost up to 1874 was over 2,000,000 thalers, or, say, $1,500,000 gold, which would be something over $51 per running metre. Now, assuming this sum to have been expended in equal annual installments of 60,000 thalers through 33 years, and calculating compound interest at 4 per cent annually, we have, as the total cost, $M = \frac{a(1+r)^n - a}{r}$; a being the annual payment, r the rate of interest, and n the number of years. Putting $a = 60{,}000$ thalers, $n = 33$, and $r = .04$, m becomes in round numbers 3,972,600 thalers, or, say, $3,000,000, thus tending to show that the cost of the adit has been doubled by the delay. Now, it has been seen that the depth of this adit where it reached the workings was only some 94 metres (308 feet) below the Anna adit. Connections with other mines at the highest have given a drainage of only 152 metres (499 feet). The object of this adit is exactly similar to that of the Sutro Tunnel, five miles long, and which meets the workings nearly 610 metres (2000 feet) below the surface. If the economical Germans are willing to spend so much money and time

* Extract from a "Paper on the Rothschönberger Stollen," by R. W. Raymond, read before the American Institute of Mining Engineers, May, 1877. Vol. VI., Transactions of the Institute. Also see "Engineering and Mining Journal," New York, vol. xxiv., pp. 308 and 330, October 27 and November 3, 1877.

in making an adit 30 miles long, for the sake of gaining 300 to 500 feet in depth of drainage, it is evident that the age of deep tunnels is not over; and the critics who have expressed doubts of the usefulness of the Sutro Tunnel may find reason to revise their views.

An inspection of the progress tables of the Rothschönberg and of the Sutro tunnels will show the striking contrast attained in progress between the one driven under the old Saxon system of hand labor and black powder, and the modern type of machine-drills with dynamite.

Other German adits have been driven in the Harz: among them,

The 13 Lachter Stollen, commenced	A.D.		1525
" Frankenscharner	"	"	1548
" 19 Lachter Stollen	"	"	1551
" Raben Stollen	"	"	1573

But the famous ones in the Harz have been the Deep George and the Ernst August adits.

The former was driven in 1777 to 1799; the main tunnel was some 10,524 metres (34,529 feet) long, and the total length of the main tunnel with all the branches was some 18,240 metres (59,845 feet). It was driven through graywacke and argillaceous slates belonging to the subcarboniferous strata, the so-called "Kulm." It added a total depth of drainage of about 140 metres.

The Ernst August Tunnel * was driven below the Deep George in 1851–1864. The main tunnel is some 10,429 metres (34,218 feet) long, but the entire length of the adit is some 22,692 metres (74,452 feet); the rock is similar to that in the Georg Stollen. The tunnel was driven $3\frac{36}{100}$ metres high by $1\frac{68}{100}$ metres wide, on a grade of $\frac{675}{1000}$ per mille. The total cost was some 570,000 thalers. This is one of the most famous German adits ever built. The engineer in charge was Mr. E. Borchers, of Clausthal.

Now, this tunnel, over 30,000 feet long, was driven to afford drainage for a total depth at the mines of about 50 (Oberharz) lachters, or, say, 315 feet.† As a feat of rapid work in its construction, the following is quoted in the pamphlet before cited, p. 29 ("Der Ernst-August-Stollen am Harze," Clausthal, 1864):

"With average rock the rate of advance in 7-hour shifts was 3·84 metres per week, or 192 metres per year. By cutting the time of work down to 4-hour shifts, 5·76 metres were excavated per week, or 288 metres per year; and during the last three weeks, by taxing the workmen very much, a rate of 7·68 metres per month was attained, equal to 384 metres per year with the best miners." (Black powder and hand-drilling of course.)

These examples of German adits have only been cited to show us by contrast what our American Sutro Tunnel is. The fuller tables at the end of this chapter will more plainly illustrate the question.

* See "Der Ernst-August-Stollen am Harze," Clausthal, 1864.

† 1 Oberharzer Lachter = 1·9198 metre.
" " = 6·298673 English feet.
" " = 8 Spann (Achtel Lachter) of 10 inches.
" = 0·91753 Prussian Lachters.
" = 6·116869 Rhine feet.
(E. Borchers.)

PART V.

THE MONT CENIS TUNNEL.

THE Mont Cenis Tunnel pierces the northern wing of the Cottic Alps, between the Tabor on the south-west and Mont Cenis on the north-east, and passes through and under the Col de Fréjus. As the tunnel is situated about 15 miles (24 kilometres) to the south-west of Mont Cenis, it has been said that it should more properly bear the name of Fréjus.

HISTORY.

We have seen (p. 316) that the project of tunneling the Hoosac Mountain in America was broached in 1826, and that Laommi Baldwin, a distinguished civil engineer in those days, made a report in favor of tunneling the mountain when locating the proposed canal from Boston to the Hudson; we have further seen that the project was finally perfected after railroads had come into use, the tunnel being commenced in 1854 and completed in 1876.

The Mont Cenis Tunnel was first proposed not by a scientist, nor by an engineer, but by a humble Piedmontese peasant, dwelling in the village of Bardonnèche, Giuseppe Medail by name. In 1838, he submitted to King Carlo Alberto a plan for piercing the mountain between Modane and Bardonnèche. Medail had found that the bed of the Arc and of the Bardonnèche brook lie in the same level, and that the Fréjus Mountain was the narrowest part of the western chain of the Alps. Some years later (1841), Medail also submitted his plan to the Chamber of Commerce of Chambery, but without success.

In 1845, the Piedmontese government detailed Mauss, a Belgian engineer (distinguished from having constructed a set of successful inclined planes near Liège), and Sismonda, an Italian geologist, to examine the plan. Although they, and engineers generally, acknowledged the importance of the project, its magnitude caused them to pause in a decision: to pierce a mountain 39,372 feet (12,000 metres) long, and located at some points some 3937 feet (1200 metres) below the surface, was a departure indeed from the tunneling of former days. Mauss invented a cutting machine to use in piercing the tunnel, but this machine we have seen, in Chapter V., p. 190, was finally discarded in 1850. The great trouble was to provide for ventilation, and this was finally met by the physicist Colladon, of Geneva, who in 1852 proposed to apply compressed air as a motor, and to use the mountain streams as a source of power in compressing it. Bartlett, in 1854 (as we have also seen in Chapter V., p. 210), invented a drill for the tunnel, which proved a great step in advance of Mauss's cutter, it being a true percussion drill; it, however, was to be driven by steam, and shared the fate of Haupt's somewhat similar project in America. (Haupt also proposed using steam with his early drill.)

Finally, Sommeiller invented a drill that was partly original, and partly perhaps an improvement on Bartlett's idea. With it compressed air was to be used, and it ultimately proved to be the key which unlocked the stone portals of Mont Cenis. This air-compressing idea was worked up by the Italian engineers, Grandis, Grattoni, and Sommeiller, in the decade from 1850–'60. A commission of scientists was appointed by the Italian government to consider the result of these experiments. It consisted of Senator Des Ambrois de Novado, Prof. Giulio, Colonel Ménabréa, and Engineers Ruva and Sella. After a full trial with the machines then known, held at Coscia, near San Pier d'Arena (not far from Genoa), the commission made a favorable report on the use of compressed air.

The importance of the tunnel scheme was at once recognized by the sagacious Cavour. Paleocapa, the blind Minister of Public Works, and Sella, Minister of Finance, also supported the project. Finally, an act passed the Piedmontese Parliament on June 29th, 1857, by

which the government agreed to furnish one half the cost of the tunnel, estimated at 40,000,-000 lire (= 40,000,000 fr. = $7,760,000). (This was three years after the act of 1854, by which the Massachusetts State Legislature made their first appropriation of $2,000,000 = 10,-280,000 fr. toward Hoosac Tunnel.) The balance of the cost was to be borne by the Victor Emmanuel Railroad. Later, the entire cost of the tunnel was borne by the Piedmontese government. (Note how closely this parallels the history of the relationship of Massachusetts to the Troy & Greenfield Railroad and Hoosac Tunnel.)

Finally, after the creation of the kingdom of Italy, when the dukedom of Savoy was ceded to France, Cavour, in 1862, made a treaty with the French government, according to which half the cost of construction was to be refunded to the Italian government by France after the completion of the tunnel.

The following table,* compiled by E. Bignami, is a concise historical summary of the principal events connected with the Mont Cenis Tunnel (the first date (1838) is not given by Bignami, but is taken from Zwick):

CHRONOLOGICAL TABLE OF MONT CENIS TUNNEL.

1838.—Joseph Medail's first proposal.

1841.—Medail's second proposal.

1843.—A plan for building new railroad lines from Genoa to Turin proposed by Brunel.

1844.—King Carlo Alberto charged Minister Gallina to study railroad constructions.

1845.—Cabinet order by King Carlo Alberto to Minister des Ambrois de Novado di Oulx to begin the railroad from Turin to Genoa, Alexandria, and Avona—to be built at government cost; the minister ordered engineer Heinrich Mauss, of Belgium, to examine the Alps passes to Savoy. Medail's proposal again considered. Sismonda charged with the geological examinations. Trials made at Valdocco with Mauss's rock-cutter.

1846.—Sommeiller and Grandis sent by the government to foreign countries to study railroad constructions. In the state budget, 300,000 francs appropriated for Mauss's machines.

1847.—Conclusion of a treaty between Piedmont and Switzerland for building a railroad across the Lukmanier. The 300,000 francs appropriated for Mauss's machines increased to 500,000.

1850.—Mauss's plan not supported in the subalpine parliament. Paleocapa made Minister of Public Works.

1851-52-53.—Various concessions granted for railroads in Piedmont.

1852.—Colladon proposed the use of compressed air in the tunnel.

1854.—Opening of the Turin-Susa line. Engineers Grattoni, Grandis, and Sommeiller made a proposal to use compressed air to run a hydropneumatic engine at the Giovi grade, between Giovi and Genoa. The parliament accorded 120,000 francs for a trial.

1855.—Count Cavour appropriated this sum, without regard to parliament, in employing the new system for piercing the Alps.

1856.—Concession granted to the company "Lafitte," for building a railroad through Savoy.

1857.—March.—A commission appointed, under the presidency of Des Ambrois, to report on the experiments to be made in April at Coscia, near Genoa.

1857.—August 18th.—Act passed for the tunnel through the Fréjus, and charter granted to the company "Lafitte" to build the road from Culoz to the Tessino River.

1857.—August 18th.—Formal inauguration of the work and firing of the first blast on the Modane side in presence of King Victor Emmanuel and Prince Napoleon. In the autumn,

* "Neuere Tunnelbauten," p. 11, by Dr. H. Zwick (1878).

beginning of the survey work for piercing the Fréjus. (Note that this was three years after the commencement of Hoosac Tunnel in 1854.)

1857.—November 14th.—Firing of the first shot on the Bardonnèche side.

1858.—Conclusion of the surveys.

1859.—Preparatory work at both portals of the tunnel. War between France and Piedmont against Austria. Cession of Savoy to France.

1860.—Continuation of the preparatory work, canals, reservoirs, and work-shops. Trials with compressors.

1860.—Continuation of the excavation of the tunnel by the old method.

1861.—January 12th.—Beginning of the machine-drilling on the Bardonnèche side.

1861.—June 6th.—Death of Count Cavour.

1862.—January 28th.—Beginning of machine-drilling on the Modane side.

1868.—June 15th.—Inauguration of the Fell Railroad from St. Michel to Susa.

1870.—December 25th.—Last section of rock pierced and the headings holed.

1871.—September 17th.—Formal inauguration and opening of the completed tunnel.

It is an interesting and melancholy fact, in the history of this great work, that few out of all the great men who, as scientists, engineers, or statesmen, had been prominently interested in its inception, lived to see its completion. Among those left were Grattoni and Colladon, who lived to be present at the formal opening of the tunnel, which took place September 17th, 1871, the headings having previously met December 25th, 1870; but Sommeiller, to whose persistent energy the world chiefly owes the completion of the great work, died in September, 1871, before the formal inauguration of the tunnel was held. There are few engineers whose names will live in history by his. His life-work was consummated at Mont Cenis, but his name belongs to the world at large, and his fame is written on an enduring monument,

Alpes enarrant gloriam ejus.

Location of Mont Cenis Tunnel.

Between France and Italy—*i.e.*, between the Dauphiné (Savoy) and Piedmont—rises the chain of the Cottic Alps, averaging over 6500 feet high, extending from Monte Viso to Mont Cenis—from the source of the Po to that of the Dora Baltea. The range in part consists of two parallel chains of mountains, a western and an eastern one, separated by the valley of the upper Durance. The name of the range is derived from King Cottius, who ceded his little kingdom (named after him) to Rome in the time of Octavianus Augustus.

Besides a number of footpaths and trails, two highways lead from France across the Cottic Alps into Italy: one of them, the main road connecting France and south-western Switzerland (Geneva) with Piedmont and Italy, passes from the Valley of the Rhone up from Culoz into the Valley of the Isère, thence leads off to the right into the valley of the Arc, and follows the latter upward by St. Michel and Modane to the village of Lanslebourg. It thence descends Mont Cenis with many winding turns, reaching ultimately a height of 6772 feet (2064 metres) above the sea. At this elevation it runs between the great and small Mont Cenis, and reaching the south side, descends to Italy, following the Cenise rivulet, a tributary of the Dora.

This road was the one built by Fabbroni, in 1805, for Napoleon.

It was completed in three months, 3000 workmen being employed, and by it the French descended to Italy in 1859 to conquer the Austrians at Magenta and Solferino. The above route was taken by the Victor Emmanuel Railroad as far as St. Michel. Between Susa and

St. Michel, a line of stages ran until 1868. On June 15th, 1868, the Fell Mountain Railroad began running, located in the main on the old line of the road. On this road 18 locomotives were used in the summer of 1870. One of these engines carried 60 to 70 passengers, or 20 tons of freight, at a rate of 9·3 miles (15 kilometres) per hour, and from November 1st, 1869, to May 20th, 1870, 18,896 passengers were carried across. This road, according to contract, was discontinued on the opening of the Mont Cenis Tunnel.

Construction of the Tunnel.

As to the geological formation of the ground to be passed through, the predictions of Elie de Beaumont and of Sismonda that no eruptive rocks would be found, but rather only sedimentary, mostly metamorphosed strata, belonging to the Jurassic period, proved correct.

According to Engineer Mella, the strata do not strike at right angles to the direction of the tunnel, but from north 35° east to south 35° west, dipping toward north-west at an angle of 50°, so that the tunnel pierces the strata at an oblique angle. Proceeding from Savoy to Piedmont, the following rocks were struck:

TABLE 37.

FORMATION.	THICKNESS.	TIME.
Sediment, sand, boulders, quartz, gravel	128·00 M.	Dec. 5, 1857, to April 25, 1858.
Alpine anthracite formation (slate, sandstone, conglomerate, talcose schist)	1967·35	April 25, 1858, to June 15, 1865.
Solid quartz rock	881·40	June 15, 1865, to March 7, 1867.*
Middle limestone formation, as follows:		
Anhydrite	220·50	March 7, 1867, to June 4, 1867.
Crystalline limestone	34·00	June 4, 1867, to June 21, 1867.
Talcose schist	49·30	June 21, 1867, to July 12, 1867.
Crystalline limestone	21·83	July 12, 1867, to July 23, 1867.
Anhydrite	29·73	July 23, 1867, to Aug. 3, 1867.
Limestone slate	21·20	Aug. 3, 1867, to Aug. 13, 1867.
Anhydrite	14·20	Aug. 13, 1867, to Aug. 20, 1867.
Limestone slate	896·85	Aug. 20, 1867, to March 24, 1868.
Anhydrite	70·80	March 24, 1868, to April 25, 1868.
Lower limestone slate formation	9394·00	To Bardonnèche.

On the north side of the mountain, near the village Fourneaux, the level of the tunnel lies 3946·4 feet (1202·82 metres) above the sea; on the south side, near Bardonnèche, 4381·1 feet (1335·28 metres.) By triangulation the length was fixed at 39,096 feet (12,220 metres); subsequently it was in fact found, by measurement through the tunnel, to be 40,138·3 feet (12,233·55 metres).

As will be seen, the north end of the tunnel lies 133·56 metres lower than the south end. In order, however, to obtain a flow of water toward both portals, the tunnel was given an elevation of 1338·43 metres in the middle, so that the grade toward Bardonnèche is 3·05 metres (1 : 2036), and toward Fourneaux 135·61 metres (1 : 45). The tunnel, though originally built throughout on tangent, when finally completed had short curves at either end. These were neglected at first, in order to render the alignment surer. There are, therefore, three distinct lengths to be considered:

(1) The original tunnel, as built on tangent, = 40,138·3 feet (12,233·55 metres).

(2) The amount of tunnel on tangent actually used, 37,384·8 feet (11,638·15 metres).

* The difficulties with this stratum were such that work progressed only 0·59 M. per day, instead of 1·45 as before.

(3) The portions on tangent, with the curved entrances or the final length, 42,157·3 feet (12,848·92 metres).

The amount on the original tangent not used in the tunnel when completed was 1953·5 feet (595·40 metres), which, added to the final length of 42,157·3 feet (12,848·92 metres), gives the total length of tunnel driven 44,110·8 feet (13,444·32 metres).

As to the machinery, etc., used at Mont Cenis, the Sommeiller drills and the air-compressors will be found described in Chapter V. This present account of the Mont Cenis Tunnel is intended to be rather as regards the history of the work, the location of the tunnel, the system of drilling and blasting used, and the rate of progress attained in the heading. As

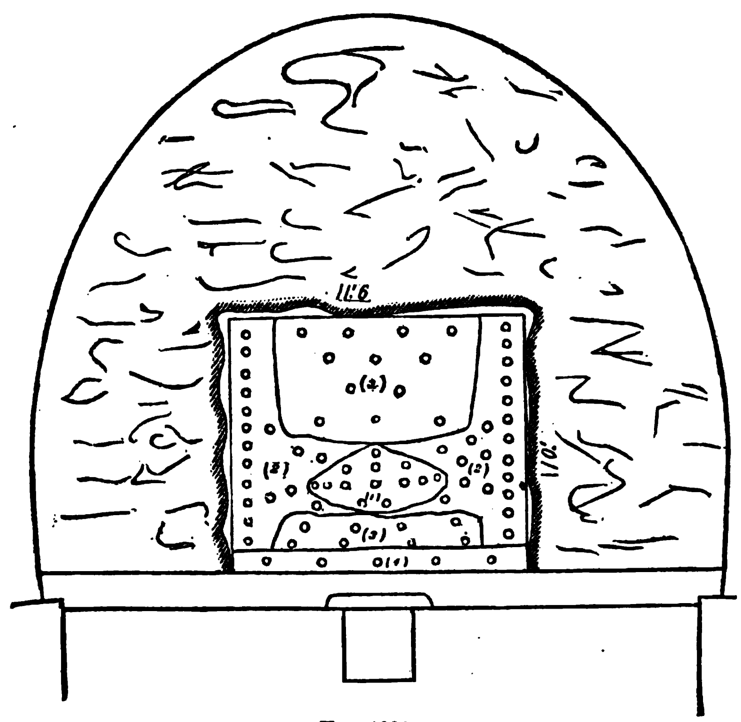


FIG. 129½.

CROSS-SECTION SHOWING POSITION OF BLAST-HOLES IN THE HEADING OF MONT CENIS TUNNEL, 1862.

to the latter, it was driven at the bottom, and, according to Mr. Sopwith's two papers* on the tunnel, this heading was at first driven about 10 feet square, the size being subsequently settled at about 9½ feet wide by 8½ feet high.

From 70 to 80 holes of about 1 metre (3·28 feet) deep were drilled into the face of this heading, the object being not so much to lift the rock by carefully-placed holes, as to shatter it with a number of them. According to Zwick,† about eight of these holes were charged at a time, the firing being done by fuse. The rock was blasted in pieces of about 3 to 4 cubic decimetres (183 to 244 cubic inches), and daily about 720 holes were blasted with the use of some 220 to 250 kilogrammes (484 to 550 lbs.) of powder. The total amount of rock broken in the tunnel was in all about 800,000 cubic metres (1,046,403 cubic yards).

The following detailed account of the system of drilling at Mt. Cenis is from Mr. Charles

* Proceedings Institution of Civil Engineers, vol. xxiii., p. 258; and vol. xxxvi., p. 1.

† "Neuere Tunnelbauten," p. 9.

E. Storrow's report* of the tunnel when he visited it in 1862: "The heading is carried forward at the bottom about $11\frac{1}{2}$ feet wide and nearly 10 feet high.

"The machines, when brought up to the work, drill 80 holes before any blasting is done. Three of these, near the centre, are large, being about 8 centimetres, or rather more than 3 inches in diameter, and are not used for blasting, but simply as an 'excavation' on a small scale, to facilitate the effect of the first blasts. Fig. $129\frac{1}{2}$ shows the position of the holes, and also shows, by the figures 1, 2, 3, 4, the order in which the four groups, into which they are divided, are successively blasted. As soon as the holes are all made, the drill-carriage and the tender are run back upon the track far enough to be out of harm's way, and protected by doors or barricades. All the holes are then loaded, except the fourth group at the bottom. Group 1 is fired; then group 2; then group 3. The lower group, 4, is then cleared of the rubbish which falls upon it from the previous blasts, is loaded and fired.

"The holes drilled by the machines are from 32 to 36 inches in depth. For the three large holes, which are not blasted, a drill is used which has a diameter of about $1\frac{1}{2}$ inches for a length of 4 inches, and is then enlarged to a cutting shoulder of about 3 inches in diameter. If the rock is very hard, drills about $\frac{1}{4}$ inch smaller are used. For the other holes, drills are used of three sizes, Nos. 1, 2, and 3, which are respectively of the diameter of $1\frac{9}{16}$, $1\frac{7}{16}$, $1\frac{5}{16}$ inches—the smallest being used for the hardest rock. Where a particularly hard rock is met with, they sometimes begin with a large drill, No. 1, and successively use smaller drills, Nos. 2 and 3, as they deepen the hole. To make eighty holes, they generally use 120 drills, but sometimes one drill will make two or three holes, and sometimes one hole will require two or three drills. The common section of the cutter at the end of the drill is Z. If the rock were more homogeneous, they would use a straight-edged cutter. The greatest difficulty encountered is the want of homogeneity, which they consider much worse than hardness. The Z section, with the rotatory motion of the drill, partly obviates the difficulty."

In 1863–'64, Mr. Sopwith gives the average working time as 6 to 8 hours for the machinists, $1\frac{1}{2}$ to 2 hours for charging and firing, 3 to 5 hours for removing broken rock, or hardly two complete shifts in twenty-four hours. The rate of work was, of course, in subsequent years, much improved, and the tables of monthly progress of headings at the end of this chapter will give the rate of advance attained. The enlarging of the heading was first effected by carrying it directly up to the roof by means of a high carriage. The top was then widened out, the arch put in, and then the sides taken out, the arch being temporarily supported by timber, according to the Belgian plan, until the abutments were built.

In 1864, Mr. Sopwith, in making an estimate of the comparative cost and rate of progress by hand or machine labor, says in his paper: "There is no doubt that establishing, as Mr. Sommeiller has done, on so large a scale, an entirely new system, without experience in its use and application, many expenses have been incurred that would be avoided hereafter . . . it appears, so far as may be judged from so rough an estimate, that by machinery a progress three times as fast as by hand labor may be effected, but at two and a half times the cost. For mining charges, in the case of a gallery for mining purposes, the comparison might stop here; but not so in the case of a railway-tunnel. For the enlarging, timbering, walling, and general charges are quantities common to both, and the proportion will be notably diminished when they are added. The estimated cost of making the Mont Cenis Tunnel was £120 per metre. It makes but little difference, therefore, whether the mining charge there is £10 or £26 per yard. The ultimate proportion of cost to put against an increased advancement of three to one would thus, instead of being two and one half to one, not exceed £126 to £110, assuming the charges common to both systems to amount to £100 per yard, which, in the case

* Report of Charles E. Storrow, embodied in the report of the Massachusetts State Commissioners on the Troy & Greenfield Railroad and Hoosac Tunnel, February 23d, 1863.

of the Mont Cenis Tunnel, they will not fail to do. In ordinary cases, to which the preceding comparisons are supposed to refer, rather than to the Mont Cenis, say, in the case of a tunnel costing £30 per yard, which is perhaps not too much to assume for a tunnel of sufficient length to make it advisable to apply machinery, the comparison would naturally be more disadvantageous than in the Mont Cenis, where the general charges are so exceptionally high. Say, therefore, in the case of a tunnel to cost £30 per yard when completed, that £5 per yard was for mining charge in the advanced gallery, and £25 per yard for general charges. By applying machinery, the mining charge would be increased to £13 per yard; and the £25 per yard for general charges might be increased to £27 per yard, as air-pipes would not be required if machinery were not introduced; the proportion of cost would then stand as 40 : 30, which would not purchase at all dearly an advancement in the proportion of 3 to 1."

These estimates are now only of interest as showing the early stages of rock-drilling in Europe. Mr. Sopwith further, in 1864, estimated the cost of construction of the tunnel at that date at about £125 per lineal yard, as follows:* "The miners were paid 2 francs† 10 centimes per day; other classes of workmen were paid 2 francs per day, and boys 1½ francs per day; so that, on the average, the rate of wages paid for labor, even allowing for the ten foremen machinists employed in the tunnel and at the pumps, did not at the most exceed 2 francs 50 centimes per day, equal to about 2*s*. (A premium, varying according to the nature of the material met, was paid to the workmen, over and above their rate of wages. See prices, page 368.) To estimate roughly then the cost of the tunnel, take 2500 men at 2*s*. per day; dividing that by 3 yards per day advancement at the two ends, gives the cost for labor under £85 per yard; and, as the labor of all the workmen was included in the 2500, £40 per yard was a liberal estimate for the cost of materials, etc., for walling and finishing the tunnel. This would give £125 per yard" (this was in 1864). Further Mr. Sopwith says, "The rates formerly attained by the Piedmontese miners (and perhaps there were no better in Europe) were known. It was found that during three years or four years of hand labor, the average progress was not more than about 18 inches per day, while the results in similar works, as obtained from machine labor, at the time of the author's visit, and maintained during the month of June, 1863, and since that time, were 4·7 feet, affording at once a comparison in favor of the machine of at least 3 to 1."

By the time the Mont Cenis Tunnel, however, had been completed, the comparative rate was raised to 5 to 1, and, as stated in the chapter on rock-drills, that figure may now (1882), in view of the more recent experience gained at Hoosac, Musconetcong, Nesquehoning, Sutro, and St. Gothard, be taken as a safe figure. It has indeed been considerably exceeded (see tables at the end of this chapter), but the highest figures can hardly be taken for a general estimate.

On the completion of the tunnel, it was expected that the difference of level between the French and Italian sides would have secured a steady current of fresh air from north to south. This was, however, not found to be the case, and a line of pipe of about 8 inches diameter was laid through the tunnel and filled with compressed air from two compressors run by a water-wheel at the Italian end; this pipe having cocks at short intervals, to be opened as occasion may require. The tunnel is lighted with oil lamps, one being placed at every 500 metres, and marked legibly with the distance in kilometres from the Bardonnèche entrance.

The arching is carried throughout the tunnel, with the exception of about 300 yards in quartzite on the French side. There are good side-paths left on either side, of flagged stone, about 1 foot 8 inches broad. All the walling and brickwork are said to have been executed

* Proc. Inst. C. E., vol. xxiii., p. 311.

† 1 franc (gold) = \$0·194; £1 (gold) = \$4.87.

substantially and with remarkable uniformity, considering they were not commenced and carried straight forward, but in sections at several different points at the same time.

Since the completion of the tunnel, the temperature of the air in the middle has varied from 80° to 90° F. During the construction, a spring located at a distance of 7000 metres from the Bardonnèche entrance was found to have a temperature of 84° F.

Zwick * gives the final cost of the tunnel as about 75,000,000 francs, or, say, in round numbers, $15,000,000. The act of August 15th, 1857, which granted the building of the tunnel to the Piedmontese government, calculated the cost at 41,400,000 francs, of which 20,000,000 were to be paid by the Victor Emmanuel Railroad after completion of the work. Besides, France, after the cession of Nice and Savoy, agreed (as we have seen), in an international convention, to pay Italy 19,000,000 francs after the tunnel was completed, together with an annual premium of 500,000 francs in case it were finished before twenty-five years, provided that Italy did the work with its own men and materials. Although the tunnel was completed long before twenty-five years, a short calculation will show that the amount paid by France was only about 27,000,000 francs, far less, therefore, than half the total cost, which amounts to 75,000,000 francs, or $15,000,000; which, taken as the cost of a tunnel 12,848·92 metres = 42,157 feet in length, gives $356 per running foot.

For fuller details of the Mont Cenis Tunnel, the best papers on the subject in the English language are Mr. Sopwith's, above referred to, and a series of papers on Mont Cenis Tunnel, by Mr. Francis Kossuth, Royal Commissioner for the Railways in Italy. The latter are very full as to the surveying, geological characteristics, machinery for compressing air, rock-drills, theoretical principles of compressing air, etc. etc. They will be found in "Engineering" (London) as follows:

Vol. xi. (1871), pp. 347–377–429.

Vol. xii. (1871), pp. 37–180–193–241–283–367.

Vol. xiii. (1872), pp. 86–391.

Zwick has also given an excellent description of the tunnel in his "Neuere Tunnelbauten," and Schoen has some notes in his "Tunnelbau," 1874. See also J. Bonjean, "Le Mont Cenis, percée des Alps, Description des nouvelles Machines de MM. Sommeiller, Grattoni et Grandis." 1866. "Conte-Rapport au Ministre des Travaux publics sur le Percement du grand Tunnel dês Alpes," 1863. Devillez, "Des Travaux de Percement d'un Tunnel sous les Alpes et de l'Emploi des Machines dans l'Intérieur des Mines," 1863. "The Mont Cenis Tunnel: Its Construction and Probable Consequences," London, 1873. "Trafora delli Alpi," etc., Turin, 1863. Oppermann's "Nouvelles Annales de la Construction," etc., vols. for 1869, p. 71; 1871, pp. 79, 92 and 95.

Since the publication of the above description in the first edition of this work it is said that the base of the Mont Cenis Tunnel at the French entrance shows such ominous signs of sinking that the Paris-Lyons Mediterranean Railway Company intend to have another entrance to the tunnel bored, which is to be situated at about 1 kilometre's distance from the present entrance, and is to reach the old tunnel at a spot about 600 metres from its mouth. The work has already been commenced.

PART VI.

THE ST. GOTHARD TUNNEL.†

ORIGIN AND LOCATION.

THE idea of an alpine railroad over the St. Gothard was started in 1840–'50. It assumed

* "Neuere Tunnelbauten," Leipzig, 1873, p. 11.

† The following description of St. Gothard Tunnel (except the contract prices cited pp. 360 and 361) was especially prepared and contributed by Mr. J. Kauffmann, Inspecting Engineer of St. Gothard Tunnel for insertion in this work. Mr. Kauffman's notes were written in German, and were translated and placed in the form here given, by Mr. Charles Kirchhoff, jr., M. Am. Inst., M. E.

a firmer aspect in the beginning of the decade 1850–'60, and under the auspices of the Swiss Central Railroad Company, with the co-operation of a number of cantons, a commission was formed, and under its direction more detailed studies were made in the matter. Accurate surveys were made, and upon these Engineer Müller, of Uri, and Chief-Engineer Locchini, of Tessino, drew up a report, the former also starting the idea of a great tunnel between Goeschenen and Airolo. These examinations were continued by Engineer Wetli, who had also taken a prominent part in drawing up the original plan. He finally put in shape a project for the entire Gothard Railroad. There, however, the matter rested until 1863, when the commission was reorganized with the aid of the Swiss North-east Railroad Company, and under the immediate direction of the then president of the road, Dr. A. Escher. A thorough set of technical and financial examinations was now inaugurated. For the technical part, Messrs. Beckh and Gerwig were engaged as experts, who published the result of their studies, plans, and calculations of costs in a detailed report. In it the piercing of the great tunnel between Goeschenen and Airolo was decidedly recommended, and they directly opposed locating it any higher in order to shorten it.

At the same time, the question of an Alpine railroad was looked into by the Italian government, Italy having a decided interest in the completion of a railroad connection with Germany. The Italian commission arrived at the conclusion that of the three routes possible, the one through the St. Gothard offered most advantages, and that it would be of the greatest interest to Italy to aid it. Germany also taking an interest in the question, and having declared her co-operation probable, in 1869, a treaty was concluded between Germany, Italy, and Switzerland, which determined the basis on which the enterprise was to be carried out, the trace (line) chosen, and the respective contributions on the part of the three states. The Franco-German war prevented the ratification of this treaty on the part of Germany until October, 1871. Germany having then signed, the organization of the St. Gothard Railroad Company was immediately carried out.

Award of the Contract.

In April, 1872, Mr. Gerwig, of Baden, was appointed chief-engineer of the Gothard Railroad, and immediately afterward bids for the execution of the great St. Gothard Tunnel were called for. Of seven bids, two only finally were really considered—the one from the Società Italiana di Lavori Publici (Mr. Grattoni at the head), the other that of M. Louis Favre, of Geneva; and of these two, preference was given to the latter because his bid was by far the more favorable for the Company. Favre's bid was 12,500,000 francs less than Grattoni's, and his time set for completing the work one year shorter. On August 7th, 1872, an agreement was therefore made with M. Favre for the execution of the tunnel, the main conditions of which stood in 1878 as follows (some alterations have been made since the original contract was signed):

Prices Paid to the Contractor, Louis Favre, of Geneva.*

(These figures are not from Mr. Kauffmann, but were obtained by the author from other sources.)

Tunnel Excavation, including drain,	per lineal metre	frs.	2800
Arch,	" cubic "	"	75
" additional for facing,	" square "	"	20
Rubble masonry,	" cubic "	"	40
Ballasting,	" lineal "	"	22
Track-laying,	" " "	"	4
Additional end-headings for alignment,	" " "	"	1500

For the arching, the cross-sections are classified as follows:

No. I. Arch springing from a point 2 metres below crown (no abutments).
" II. " " " " 4 " " " "
" III. Full arch with abutments and invert.

Nos. I. and II. have each 3 subdivisions:

a Arch without abutments.
b " with one abutment.
c " " two abutments.

* 1 franc = $0.191. 1 metre = 8.281 feet.

The prices of masonry are the following per lineal metre of tunnel:

No.	I.	*a*	Thickness of arch, 0.40 to 0.70 metre	frs.	515 to	757
"	"	*b*	" " " " "	"	675 "	1000
"	"	*c*	" " " " "	"	820 "	1200
"	II.	*a*	" " " " "	"	605 "	975
"	"	*b*	" " " " "	"	775 "	1160
"	"	*c*	" " " " "	"	880 "	1310
"	III.		" " " " "	"	1925 "	2470

For monthly estimates, the following prices are paid:

Heading	per running metre, frs.	1300	
Calotte (or leading enlargement)	" " " "	600	
Cunette of Strosse	" " " "	350	
Strosse	" " " "	450	
Enlargement—finishing	" " " "	100	
			2800
Masonry of abutments	per cubic metre, frs.	40	
Arch	" " " "	75	
Facing, in addition to foregoing	" square " "	20	
Stone on hand, measuring face only	" " " "	15 to 20	

(Fig. 130 shows the different portions of work referred to.)

At these rates, the cost of the entire tunnel would amount to about 50,000,000 of francs in all. The principal features of the contract were the following: M. Favre agreed to finish the tunnel in eight years from the date of the ratification of the agreement by the Swiss Council. Should the tunnel be completed before that date, for every day gained he was to receive a premium of 5000 francs; on the other hand, for every day after that date lost, he was to suffer a deduction of 5000 francs in the first six months, and in the next six months a deduction of 10,000 francs per diem. For the correct fulfillment of his engagements, M. Favre gave a security of 8,000,000 francs, to become the property of the company if the completion of the tunnel be retarded by more than one year. M. Favre was to make the arrangements for the execution of the tunnel according to his own judgment, and orders the machines, tools, and supplies of all kinds necessary for construction. The cost arising was to be paid by the company, to whom it was to be refunded, however, by the contractor after the completion of the tunnel, with interest at five per cent per annum. The tunnel was not, however, completed in the specified time, and there is some difference of opinion on the subject between the Federal authorities and the contractors, the latter claiming that the delay in the completion of the work was due to the tardiness of the Swiss Government in fulfilling its engagements. The tunnel, however, will, according to J. Kauffmann, be completed in October, 1881, before the railway is finished, so that no actual delay to the work will occur. The mails have been passing through it for some time, the advance headings having met on the 30th day of April, 1880.

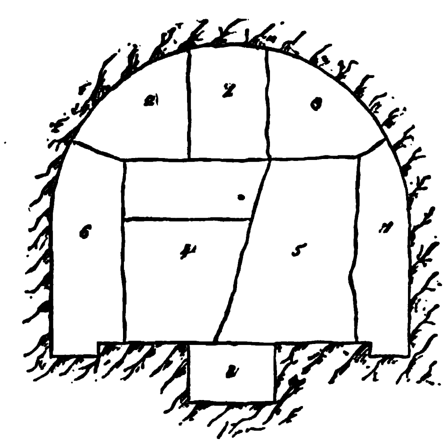


FIG 130.

1, Heading; 2 and 3, Calotte; 4, Cunette of Strosse taken out in two parts; 5, Strosse; 6, 7, and 8, Enlargement and finishing.

ALTERATIONS OF THE CONTRACT.

This agreement made with M. Favre suffered a number of alterations in the course of time, and special points were more accurately defined. By an agreement dated June 19th, 1874, the total amount of money to be advanced to M. Favre by the company for installation was settled upon at 4,000,000 francs, the payments on account of the various sections of the excavation were more accurately regulated, and for the tunnel masonry some changes giving relief were accorded, and it was further settled how the kind of arching required was to be agreed upon by the two parties. Further modifications were made in September, 1875, the

aim of which was to adhere to a certain plan of working, with the view of finishing the tunnel at the right time; furthermore, fixed normal types (see above) for the masonry were established, and for every one of these types a price per running metre (instead of per cubic metre) was agreed upon. The lowest of these prices is 515 francs; the highest (thickness of arching one metre, with invert), 2470 francs.

M. Favre himself did not live to see his great work completed. Early in the morning of the 19th of July he entered the tunnel and conducted a French engineer to the face. On his return to the machinery station in the tunnel he fell ill, and in a few moments after the attack dropped dead in the tunnel which was the crowning work of his life. He was born in Chêne-Thonex, Switzerland, in 1825, and after attending a primary school, entered business life with a modest sum. He was connected with many important engineering works in France.

Geology of the St. Gothard Tunnel.

The geological relations of the St. Gothard group have for a long time been the object of detailed studies by famous geologists. The results tend to show that the main body of the St. Gothard Mountain consists chiefly of granitic gneiss, mica schist, and hornblende schist, with the exception of the basin of the Andermatt, where jurassic limestone is embedded. The strike of the strata is north-east and south-west, cutting the line of the tunnel at an angle of from 45° to 80°. Regular observations made since the beginning of the construction have, on the whole, confirmed the truth of the above assumption. On the north side, the rock continued very hard to about 2000 metres from the portal, being granitic gneiss, then various kinds of gneissic and micaceous schists followed, after them a layer of limestone about 100 metres long, black slate and schistose gneiss. The rock tunneled through on the north side has been generally entirely dry; maximum flow of water from the tunnel per second, 30 litres (7·9 gallons). On the south side, mica schist, hornblende rock, and gneiss containing more hornblende and mica, and quartzite predominated; also, for about 1250 metres, a considerable flow of water had to be overcome, and later on, again, much water was encountered, sometimes as much as 348 litres (101·9 gallons) per second. Very great trouble was experienced during 1880 in passing through a bed of disintegrated feldspar, which swelled with almost irresistible force on exposure to the atmosphere, and threatened at one time to crush every lining that could be built in. A heavy granite arching 5 feet thick was crushed in some parts, so that it had to be renewed, and had to be supported by granite side walls 6 feet 7 inches thick.

Alignment and Grade.*

The direction of the tunnel is for the greater part of its length on tangent. In fact, it does not deviate much from the line of the meridian north and south. At the Airolo end there is a section 470 feet long on curve, radius of the curve being 984 feet. The length of the straight tunnel section is to be 48,411 feet; therefore, the entire tunnel length, including this curve at the end, will be 48,887 feet (9·26 miles). For the sake of easier verification of the line, the portion on tangent is lengthened toward Airolo by a so-called "alignment tunnel," 541 feet long. The straight distance between the tunnel-portal at Goeschenen and the portal of the alignment tunnel is therefore 48,952 feet. At Goeschenen, the tunnel will be lengthened by 164 feet beyond the portal originally assumed. The grade was so arranged in the original plan that the tunnel, from Goeschenen to the middle was to rise 5·82 per mille, then to run level for 591 feet, and then to fall toward Airolo with a grade of one per mille. As, however, it afterward proved desirable to have a heavier grade on the Airolo side to help the flow of water, the grade was increased to two per mille. The

* In the following notes, all lengths have been given in feet alone, as this account will chiefly be of interest to English and American engineers, there being copious French and German reports accessible to European engineers. (1 foot = 0·3048 metre.)

highest point of the tunnel (formerly assumed at 3781 feet above tide) is now 3786 feet. The elevation of the level of the track above tide at Goeschenen is 3639, at Airolo 3757 feet.

Mode of Working in General—Water-power Used.

The air-compressors are all run by water-power. On the north side, a reservoir has been constructed in the bed of the Reuss, above Goeschenen, from which the water is led down by a flume lined with masonry. This flume is 10 square feet cross-section, and 443 feet long. From it the water is led into a filtering reservoir to deposit its sediment, and thence into a line of iron pipe 34 inches in diameter, which takes it to the turbine. This line of pipe is 2133 feet long; it then divides into two branches, each 492 feet long, and one of which supplies each of two turbines. The entire head of water available is 279 feet, and the power attained at lowest water-mark is 1360 horse-power.

On the south side, it was thought at first that all the water necessary for working could be taken from the Tremola, a brook flowing down from the St. Gothard. At an elevation of 4544 feet above the level of the sea, the water was caught in a reservoir, and thence led to the bed of the Chiesso Brook by a channel partly lined with masonry, partly with wood, and covered. By the bed of the Chiesso, it flows to the filtering reservoir, which is 4331 feet above tide. From the latter, again, a line of cast-iron pipe 24½ inches diameter and 2762 feet long, leads to the turbines. The head of water available amounts here to 541 feet, the effect being 440 horse-power.

In time, it became obvious that the amount of water furnished by the Tremola did not, under all circumstances, suffice for the engines, and that especially in winter the supply often stopped altogether. The contractor, therefore, decided to use the water-power of the Tessino also; but on account of the slight fall of this river, he was forced to catch the water about 2½ miles above Airolo, at an elevation of 4121 feet above the level of the sea, and from thence to build a canal, partly stone arched, partly of wood, 9984 feet long of 6½ square feet cross-section, 5 per cent grade. Diameter of pipe, 2½ feet; length of line of pipe, 2229 feet; head, 295 feet. Effect may be more than 1000 horse-power. Similarly to the other constructions, the canal empties into a filtering reservoir, from which the water is again led in iron pipes to the turbines.

Arrangement of the Turbines.

Vertical Girard turbines are used as motors at Goeschenen, each requiring 300 litres of water per second, and 279 feet head, giving an effect of 250 horse-power. Diameter of turbines from outside to outside, 94½ inches; number of paddles, 80; and their velocity, 160 revolutions per minute. On the south side of Airolo, tangential wheels of bronze are used, outer diameter being 47 inches, 100 paddles, and a velocity of 390 revolutions per minute.

Air-Compressors.

M. Favre secured the scientific services of M. Colladon, of Geneva, in designing the compressor system used.

The compressors (System Colladon) are constructed on the principle of the double-acting pump, and they have a special appliance to admit a circulation of cold water, partly in the piston and the piston-rod, partly around the walls of the cylinder, thus keeping the compressed air cool. At Goeschenen, the compressor-cylinders have a diameter of 16½ inches, the stroke is 25½ inches; and the air is compressed to 7 atmospheres pressure. At Airolo, the diameter of air-cylinders is 17 inches, stroke 18 inches. (See Chapter V.) Up to

1876, the number of compressors at each end of the tunnel was 15; these were divided into 5 groups of 3 cylinders each, so that every group was put in motion by one turbine. The increased use of mechanical drilling in the tunnel made it desirable to increase the number of the compressors still more, and so, in 1876, four new, somewhat larger and more powerful, compressor cylinders were set up on each side, each pair of two being run by a turbine. The compressed air is led from the compressors first to four air-tanks, each 29½ feet long and 65 inches diameter, and from these through sheet-iron pipes to the tunnel. The diameter of pipes diminishes from the portal to the face of heading; from 8 to 4 inches, and pipes of 2½ inches branch off to the single machines. It has proved advantageous to use pipes of large diameter as much as possible, because narrow pipes reduce the pressure too much. According to M. Kauffmann's experience, one should, in the construction of an Alps tunnel, begin with pipe 12 inches in diameter, and gradually come down to 4 inches at the face.

The Rock-Drills.

For drilling in the tunnel, various makes of drills have been tried. In the beginning the Sommeiller and Dubois-François were chiefly used; later, the McKean and Ferroux were adopted; and finally, on the north side, chiefly Ferroux drills, and on the south side McKean drills were used. A McKean drill costs 3000 francs; a Ferroux drill, 1500 francs. The latter is simpler, and therefore requires less repair; on the other hand, it consumes a little more air than the former. The number of blows depends upon the pressure; in gneissic mica-schist, the progress has already, with 1½ atmospheric pressure, amounted to about 10 feet in 24 hours. Then the number of blows is about 180 per minute. For mounting these drills, carriages were constructed which move forward on rollers and are pushed up to the point of attack on tracks in the tunnel. Each carriage will carry from 6 to 8 drills. The work of drilling at any point is carried on in the following manner: For every set of rock drills there are needed on an average 1 foreman, 4 miners, 2 machinists, 8 helpers, and 1 boy. After a blast has been cleared away, the carriage with the drills is run up to the face. Two trucks accompany them, one carrying a tank of water, and the other a number of drills. Fig. 103, Chapter V., shows a carriage with drills attached. The carriage being at the face, the drills are brought into position, and the carriage-wheels blocked. Connection is then made with rubber hose between the large air-pipe and a small tank at the back end of the drill-carriage. From this tank, smaller rubber hose leads to the single drills, the air being turned on by cocks; water is injected into the holes under pressure of compressed air. The depth of the holes varies, according to the nature of the rock, from 2 feet 7 inches to 4 feet 3 inches, and in one point of attack about 13 to 18 of them are drilled: first, the middle ones directed vertically against the face, then those of the bottom and of the top at angles from 60° to 85°. All the holes being drilled, the carriage and the trucks belonging to it are drawn back for about 262 feet, and placed on a switch. Then the second part of the work commences—the charging, firing, and clearing away, for which, on an average, 22 men are necessary. (The large number of men in so small a face is caused by 6 cars being brought on at once, in order to gain time. The *débris* is carried on over the cars to the last one.) Every hole is charged with dynamite, and is prepared for firing by a Bickford fuse. The fuses are not made of equal length, so that blasting in sections results when all the holes are lit at the same time, the first being the middle, then the upper, and last the lower row of cartridges. The charge per hole amounts on an average to 800 grammes (1 lb. 12 oz. avoir.) dynamite (of 75 per cent nitro-glycerine). The shots being fired, a strong current of compressed air is blown to the face for the sake of ventilation, and then the clearing of the loose rock is taken in hand. The *débris* is loaded, as described above, with the aid of baskets, into cars standing ready on a track, and in them carried away.

Figs. 131, 132, and 133 are from the "Rapport Trimestriel No. 3, du Conseil Fédéral Suisse," etc.; they show the system of firing. The three middle holes (shown by circle and

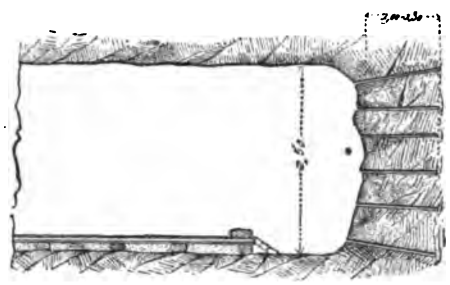


FIG. 131.
Longitudinal Section of Heading.

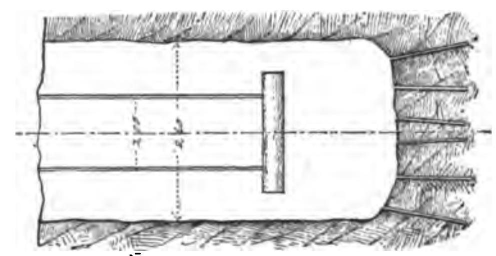


FIG. 132.
Plan of Heading.

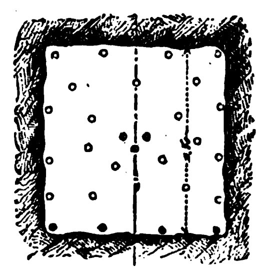


FIG. 133.
Face of Heading.

ARRANGEMENT OF SHOT-HOLES, ST. GOTHARD TUNNEL.
⊙ 1st discharge; ○ 2d discharge; ● 3d discharge.

dot) are fired first, then the side and top holes (shown by circle), and finally the bottom holes (shown by black dots).

DIVISION OF THE WORK OF CONSTRUCTION.

The system chosen by the contractor for driving the tunnel is at both ends the Belgian, the work being begun by driving in advance a heading at top of the tunnel; then this top heading is enlarged at both sides, and finally the excavation is sunk down to the bottom of the cross-section. The execution of this system, however, does not go on in exactly the same manner at both ends of the tunnel. At the north side, there are two distinct levels, the advance heading (French, "Calotte;" German, "Richstollen"), and the bottom cut ("Cunette du Strosse"—"Sohlenschlitz.")

The top heading proper was driven by machinery from the beginning, or at least as soon as the plant was in such shape as to permit it, the other parts at first by hand. The number of compressors having been increased, it became, however, possible to extend machine-drilling to other parts also, and later, besides in the face of the top heading, drill-carriages are placed at six other points, four in the side enlargements of the top heading (two on a side) and two in the bottom heading. This bottom heading (or rather cut) is not driven in the middle of the tunnel, but on the east side, and its enlargement to the full profile has hitherto been done by hand. At the Airolo end, where, on account of the strong flow of water, a good deal more timbering had to be put in, the work is done in three levels. After the top heading has been driven ahead and enlarged at both sides, the heading is deepened at one side to a certain depth; and this deepening is gradually carried out over the entire width of the tun-

nel, then the bottom heading is taken in hand, and, finally, the full area excavated. At this end, machine-drilling was in 1877 used at five other points of attack, besides the top heading—*i. e.*, at the side enlargements of the top and in deepening.

A number of pumps, run by compressed air, carry away the water from points where it does not naturally flow. Provisionally, the water has been carried off also in channels especially blasted out, or by wooden troughs; the final drainage will be through a large arched sewer below the bottom of the tunnel located on the left. The broken rock was at first run directly in the cars down a slope from the top heading to the bottom of the tunnel; later, arrangements were effected to dump directly from the upper cars into cars standing ready on the lower level.

In order, however, to transport the tools, etc., used for machine-drilling, and the machines themselves, also the arching materials, from the lower to the upper level, special hoisting appliances were constructed and set up, by which a platform could be lifted and lowered by the pressure of water at 30 atmospheres. Latterly, besides these hoisting appliances, slopes have again been constructed, in order to admit of transportation in case the elevator should not work. As far as the cars must be moved on the level of the top heading, they are partly pushed by hand, partly drawn by horses. On the bottom level, however, transportation is effected by locomotives run by air compressed to 12 atmospheres. The air for the rock-drills is compressed to 7 atmospheres. This, by special compressors, is brought to 12 atmospheres, and then led into reservoirs, from which, through a separate line of 2½-inch pipe, it goes into the tunnel, from which the locomotive is supplied at certain places. These locomotives are filled with hot water, through which the air passes, in order to avoid cooling in expanding. The air gets into the cylinders with at most 4 atmospheres pressure. This ingenious contrivance was devised by Mekarsky, an engineer at Paris. This locomotive has a tender, to which is coupled an eight-wheeled truck, carrying an air-tank, and this tank is filled through rubber tubes connecting with the large pipe.

Effect of the Rock-Drills.

It has been already noted that at every attack a number of holes are drilled, the depths of which vary from 2′ 7″ to 4′ 3″, but which, on the average, may be assumed at 1·1 metres, or, say, 3′ 7″ each. (See tables at end of this chapter.) This work requires from three to four machines, and each attack or drilling heat takes, on a minimum, three hours, which may be increased, according to the nature of the rock and the amount of air at disposal, to five hours or even more. The time necessary for charging, firing, and clearing away varies from three to four hours per drilling heat. If the work passes off smoothly throughout, four sets of holes may be drilled in twenty-four hours, and with each an advance of one clear metre (3·28 feet) of heading, driven so that the daily progress attainable in the heading may be assumed as 4 metres (13 feet) at each end, in rock such as gneiss. In fact, monthly advances of 120 and even 133 metres (394 to 436 feet) have been reached. (See tables at end of this chapter.) The amount excavated in the top heading may, according to these assumptions, be placed daily at 26 to 33 cubic yards. In the other parts of the working, no average figures can be given, because the work is done partly by hand and partly with machines, and, in the latter case, sometimes more, sometimes fewer, points of attack are worked at the same time. Here, too, the work can be done more cheaply, because there are any number of points of attack at disposal. The time required for a single machine to drill a hole one metre deep averages about one hour. In especially favorable cases, it has been reduced to forty minutes, while, under unfavorable circumstances, it has gone as high as two and a half hours. Of the machines coming into use, about 3 to 4 per cent per month require repairs. With ordinary

rock (middling hard gneiss), three to four drills are used in drilling each hole, and during a month from 3000 to 5000 of them in the heading alone.

Accidents.

Unfortunately, the construction of the St. Gothard Tunnel shows a pretty large number of accidents, more or less serious, especially in the year 1876. While, in 1875, the number of accidents causing death were 16, causing injuries 47, the figures rose in 1876 to 24 and 81 respectively. The most frequent causes of these accidents were: unexpected explosions of dynamite, from cartridges in the second and third blasting rounds having missed fire, owing to the fuse being torn away by the first round. Although, after firing, the blasters are forced to make an examination, a mistake happens now and then. Accidents also occur from rock falling down into the tunnel (especially in granite and the loose rock under the Andermatt); men have been run over by cars, and others hurt by falling down from the upper level into the lower, though very rarely; after the bottom heading had been laid entirely at the left side-wall, this did not occur at all. The bursting of air-pipes also has been the cause of some hurts being received.*

Cost of the Work.

Most of the work is contracted for by the gangs per running metre. Besides the fixed prices, premiums for extra work beyond a certain amount are paid. The single workmen share the profits in the proportion of their different days' wages. The contract prices amount, per running metre of heading in gneiss, 7·2 square yards (6 square metres), to

Drilling	75 frs.†
Transportation	50 "
Dynamite used	50 "
Fuse, baskets, oil, repairs of rock-drills, transportation of same	55 "
Total	230 frs.

The Cunette du Strosse, 15·5 square yards (13 square metres), amounts similarly, per running metre, to .... 260 frs.

The side enlargement of the upper level, 47·8 square yards (40 square metres), per running metre,

Drilling and transportation to	200 frs.
Dynamite	70 "
Fuse, baskets, oil, repairs of rock-drills, drills, transportation of same	70 "
Total	340 frs.

The bottom enlargement in granite costs per cubic metre, every thing included, 30 francs; in gneiss, probably 20 francs. Masonry is paid by the cubic metre. Rough, undressed masonry, foundations, and side-walls, including mortar, 18 francs; arching, exclusive of cost of blocks, but with transportation, per cubic metre, 22 francs. The "moellons" of granite well trimmed, cost, in stock-yard, from 55 to 60 francs per cubic metre. To these figures add

* Since the first edition of this work appeared the disease and mortality among the laborers in the St. Gothard Tunnel are represented as having been excessive. The distance between the entrance to the tunnel and the places where the perforators were at work, which was nearly five miles on the north side, coupled with the frequent freezing of the compressors, rendered ventilation extremely difficult; and the air was further fouled by frequent explosions of dynamite, the some 500 oil lamps and the exhalations of 400 men and 40 horses, working in a temperature of 80 to 95 degrees. The men died in large numbers of a peculiar disease, called tunnel trichinosis, from the presence of an entozoon in the intestines. Three or four months' labor in the tunnel brought on the disease, and twelve months generally made the laborer a confirmed invalid. The symptoms were yellowness of skin, features drawn, eyes half closed, lips discolored, skin humid, gait difficult, and digestion destroyed.

† 1 franc = $0.194.

for cost of installation, general administration, and preparation, about 6,500,000 francs, or, say, 450 francs per lineal metre of tunnel.

As to *changing the system*, it is out of the question. It has proved completely successful, as was to be expected, the advance headings meeting on the 30th of April, 1880.

The working section is very large at both ends, about 2000 metres. (This is not, of course, the area of one face, but of the many different places of attack that are carried on simultaneously.) These will be reduced, as more of the whole tunnel is finished than the advance of the heading amounts to. The two working levels, the lower and the upper, are absolutely indispensable for unobstructed transportation; with the English system,* one could not attain the effect with so much stoppage at the chutes and blasting away of the intermediate bank between the two headings, not to speak of the accumulation of water in the lower heading.

Subletting Tunnel Contracts.

The above communication from Mr. Kauffmann is of great interest, as a personal and authoritative account from the inspecting engineer of our greatest modern railroad tunnel. The system of subletting the work to which he refers, we have seen, was also pursued at Mont Cenis, and in the account of the Sutro Tunnel, we have the same thing there. Mr. F. Rinecker, civil engineer, of Würzburg, Germany, writes the author that "this system of subletting the work to the gangs is used very generally throughout Europe. As a rule, only the labor, as such, is let to them, materials being furnished by the contractor. Sometimes, to avoid waste—for instance, in the use of dynamite—the materials are included, being furnished for a certain price, and the value of the quantity consumed deducted, in paying the amounts due.

"These sub-contracts are entered into either with the whole gangs or with the miners only; and sometimes simply with the bosses. The price is fixed for a certain part of the work —say, for instance, for the heading so much is fixed anew from pay-day to pay-day per lineal metre of heading driven, the rate changing each month with the variation that may occur in the character of the rock.

"Generally, the gang fixes the proportionate rates to be paid to the different workmen—miners, of course, being rated higher than helpers. Any surplus they may gain is then divided among them in proportion to these fixed rates. Sometimes, as in headings, a certain amount of work to be done in a certain period will be fixed, and then an extra quantity will be paid for overwork done in the same period. The arrangement suits both contractors and men, it acting as a safeguard against laziness on the part of the latter."

With regard to the system at Mont Cenis, Mr. Storrow† thus describes it as in vogue in 1862, when he was there:

* As to this comparison of the Belgian with the English system, perhaps a fuller review would show that Mr. Kauffmann's remark, though doubtless true in the direct sense in which he speaks, is not to be taken as of general application. The English system he has in view is simply the application of it to rock-work—*i. e.*, driving first a bottom heading, breaking up into the roof at several places, and working the top down. But the distinctive features of the English system come into play in ground where the Belgian system is less applicable—*i.e.*, in clayey soil, etc., where drawing-bars are used, and the method of enlarging and arching in connection therewith.

† Report of Charles S. Storrow on "European Tunneling," embodied in Report of Massachusetts State Commissioners on Troy & Greenfield Railroad and Hoosac Tunnel, February 28th, 1863.

"....Thus we have for a day's work at the heading:

60 men (2 gangs of 30)	at the machines.
8 men and boys	to load and blast.
20 " " "	to remove the *débris.*
88 workmen.	

"These men are not equally paid. The prices range from 1.50 francs per day for boys to 5.50 for the best mechanics. The men who blast have four francs per day. Mr. Borelli thought the average price of the whole would be about 3.50 francs, or 70 cents per day.

"It is a great object to induce these men to work as expeditiously as possible. In order to encourage them to do so, premiums are paid for extra speed. It has been stated that to drill the holes requires from five to seven hours. If the gang at the machines can complete the holes in less than six hours, they all receive as a gratuity one quarter of a day's wages—*i. e.*, they receive pay for one and one quarter days instead of one day. If the work is completed in less than five hours, they all receive one and one half day's wages. This has been accomplished, but it is a very rare occurrence. Energetic and rapid work, therefore, insures them fewer hours of labor and more pay. The completion of the task is the work for the day. At first a premium was paid on the advance of each machine. It was found that the men interfered with each other, every one driving his own machine, and, if need be, to the inconvenience of his neighbor. Now the premium is for the whole gang. Therefore, every one is interested, not to hinder but to assist his neighbor; and if an indolent or careless workman is among them, his companions soon find him out. There is a similar system of premiums for extra rapidity in removing the materials after blasting; but there is none for the men who blast. Their labor is not of long duration, and they are well paid. For them, a premium on speed would lead to haste, carelessness, and accident. As so much depends on the skill, assiduity, and co-operation of the workmen, this system of premiums seems to be very wisely adopted."

Mr. Sopwith, in his paper on Mont Cenis Tunnel,* says, that in February, 1864, the premium was as follows, the standard being then 1 metre of lineal advance per day:

For $1\frac{1}{10}$ metres	$1\frac{1}{10}$ day's wages paid.
" $1\frac{1}{5}$ "	$1\frac{1}{5}$ " " "
" $1\frac{3}{10}$ "	$1\frac{3}{10}$ " " "
" $1\frac{4}{10}$ "	$1\frac{1}{2}$ " " "

The general rates of wages in Switzerland since 1870 (according to Mr. F. Rinecker, Würzburg) have been:

Foreman (or walking boss)	7.00 to 8.00 francs.	All per shift of 8 or 12 hours as the case may be; almost all the work being done not by day's labor, but the above wages earned pro-rata by the work being taken on sub-contract by the gang.
Boss of Gang	5.50 " 6.00 "	
Miners	4.50 " 6.00 "	
Carpenters, Masons,	4.00 " 5.00 "	
Engine-drivers	4.00 " 7.00 "	
Firemen	3.80 " 5.00 "	
Laborers	2.80 " 4.00 "	
Boys	2.00 " 2.50 "	
Horses	5.00 " 7.00 "	

* Proceedings, Institution of Civil Engineers, vol. xxiii., p. 258.

Taking all circumstances into consideration, it is believed in Europe that for *hand-drilling*, the dimensions of heading, giving the greatest economy in price with the greatest progress possible, are:

In soft ground.......................... about 6 × 6 ft. (1·80 × 1·80 m.)
" very firm ground........ about 8 ft. 10 in. × 7 ft. 10 in. (2·70 × 2·40 m.)

THE BOETZBERG TUNNEL.

We are indebted to Mr. J. Kauffmann for the following prices paid at the Boetzberg Tunnel, built 1871–'75, in the Swiss Jura Mountains, on the short line between Bâle and Zurich. Mr. Kauffmann held the position of superintending and constructing engineer. The total length of the tunnel was 8288 ft. (2526 m.), the grade falling 0·8 ft. in 100, from north to south. There was one shaft 472½ ft. (144 m.) deep. The material passed through comprised muschelkalk of irregular stratification, keuper, lias, jurassic limestone, and very extensive beds of molasse marls (mergel). With a few exceptions, all the workings were almost dry. The main heading was driven at the bottom, and the English system of timbering with drawing-bars was used in enlarging and arching. This heading was driven 6.9 ft. (2.10 m.) high, 7.9 ft. (2.40 m.) wide in the clear at the top, and 8.9 ft. (2·70 m.) at the bottom. The work was all done by hand labor, with two men to a drill, the progress being from 1·6 to 3·9 ft. (0·50 to 1·20 m.) per 8-hour shift. The tunnel was arched throughout, the arch varying from 1·2 to 2·5 ft. (0·38 to 0·75 m.) thick. The abutments and about 4·9 ft. (1·5 m.) above springing line of the arch were of rough hammer-dressed rubble masonry; the arch was of cut-stone, laid in the best hydraulic cement. There was no invert.

All the work was done on the small contract system above noted, the work being let from time to time to separate gangs. For the running metre (3·281 feet) of heading, including transportation and the work of timbering (the timber was furnished to the gangs), the following prices were paid:

In Molasse and Lias Marls	90 fr.*
" Jurassic Limestone (no timbering)	110 "
" Muschelkalk " "	100 "
" Very hard Limestone " "	130 "

The top heading was smaller and its prices correspondingly lower. The price for enlargement per running metre was from 250 to 290 francs. The tools were furnished by the company, and also all repairing was done by the company. The price per running metre for masonry (labor only) was 175 francs. At these prices, the miners and masons earned about 6 francs per shift. The bottom heading, as noted above, was driven in 8-hour shifts, the remaining work in 10- and 10½-hour shifts.

The whole tunnel, exclusive of permanent way (ballast and tracks), cost 1450 francs per running metre for construction. Adding salaries of engineers, etc., makes the total final cost 1500 francs per metre, or, say, $88\frac{70}{100}$ per running foot.

*1 Franc = $0.194 gold.

PART VII.

TABLES SHOWING RATE OF ADVANCE, ETC., ATTAINED AT THE NESQUEHONING, MUSCONETCONG, HOOSAC, SUTRO, MONT CENIS, AND ST. GOTHARD TUNNELS.

NESQUEHONING TUNNEL.

TABLES OF PROGRESS, RATES OF DRILLING, AND POWDER USED.

TABLE 38.

*South Heading.**

MONTHS.	Number of Holes.	Length of Holes bored.		Average depth of Holes.		Amount of Powder used.		Amount of Rock broken.		Powder used.		Length of Holes.		Lineal Progress.		MATERIAL.
		Feet.	Metres.	Feet.	Metres.	Pounds.	Kilogrammes.	Cubic yds.	Cubic metres.	P'nds per cubic yd.	Kilogr. per cub. m.	Feet per cubic yd.	Metre per cub. m.	Feet.	Metres.	
April, 1870........	1,060	2,740	835	2·5	0·76	1,125	510	413·0	317·5	2·7	0·94	6·6	1·54	73·6	22·3	Conglomer'te.
May, "	2,595	6,698	2,042	2·6	0·79	2,725	1,236	781·0	601·4	3·5	1·22	8·6	2·01	138·0	42·2	"
June, "	2,911	6,779	2,066	2·3	0·70	4,200	1,905	589·0	452·8	7·1	2·47	11·5	2·69	104·0	31·7	"
July, "	2,373	5,862	1,787	2·4	0·73	4,275	1,939	553·5	425·5	7·7	2·68	10·5	2·46	97·5	29·8	"
August, "	2,245	5,179	1,554	2·3	0·70	2,750	1,247	464·7	357·2	6·0	2·09	11·1	2·60	82·0	25·0	"
September, "	1,993	4,920	1,500	2·5	0·76	2,625	1,190	410·8	315·8	6·4	2·23	11·0	2·78	72·5	22·1	"
October, "	2,291	6,052	1,845	2·6	0·79	2,525	1,145	520·0	399·7	4·9	1·70	11·6	2·71	91·0	27·7	"
November, "	1,907	5,054	1,541	2·6	0·79	2,700	1,224	586·5	450·8	4·6	1·60	8·6	2·01	103·5	31·5	"
December, "	1,876	4,638	1,414	2·5	0·76	2,400	1,088	442·0	339·8	5·4	1·88	10·5	2·46	73·0	23·8	"
January, 1871........	2,079	5,438	1,658	2·6	0·79	2,900	1,315	496·0	381·3	5·8	2·02	11·0	2·57	101·0	30·8	"
February, "	2,485	6,161	1,878	2·5	0·76	2,825	1,281	530·0	407·4	5·3	1·84	11·6	2·71	93·5	28·4	"
March, "	2,414	6,043	1,842	2·5	0·76	3,400	1,542	589·5	453·0	5·8	2·02	10·2	2·39	104·0	31·7	Red Shale.
April, "	1,901	6,114	1,864	3·2	0·98	3,006	1,361	890·0	684·1	3·4	1·18	6·8	1·59	157·0	47·9	" "
May, "	1,743	5,793	1,766	3·3	1·01	3,600	1,633	928·0	713·4	3·9	1·36	6·3	1·47	164·0	50·0	" "
June, "	1,947	5,651	1,722	2·9	0·88	....	....	850·2	653·5	....	....	6·6	1·54	143·5	43·8	" "
July, "	1,288	3,580	1,091	2·9	0·88	....	....	521·0	400·5	....	....	6·9	1·61	92·0	28·0	" "
August, "	1,414	4,383	1,336	3·1	0·94	....	....	717·0	551·2	....	....	6·1	1·43	126·5	38·5	" "
September,† "	689	1,711	522	2·5	0·76	....	....	355·0	272·9	....	....	4·8	1·12	62·7	19·1	" "
Total................	35,211	92,796	28,283	....	....	41,050	18,616	10,637·2	8176·8	..	...	....	....	1883·7	574·2	
Average.	....	....	....	2·6	0·79	....	....	....	....	5·2	1·74	8·9	2·01	104·7	31·9	

TABLE 39.

Enlargement.‡

MONTHS.	Number of Holes.	Length of Holes bored.		Average depth of Holes.		Amount of Powder used.		Amount of Rock broken.		Powder used.		Length of Holes.		Lineal Progress.		MATERIAL.
		Feet.	Metres.	Feet.	Metres.	Pounds.	Kilogrammes.	Cubic yds.	Cubic metres.	Po'nds per cubic yd.	Kilogr. per cubic m.	Feet per cubic yd.	Metre per cubic m.	Feet.	Metres.	
August, 1870....	338	2,223	678	5·7	1·74	1,450	658	1,000·9	769·4	1·4	0·49	2·2	0·51	125·0	38·1	Sandstone and slate.
September, "	438	2,584	788	5·9	1·80	2,125	964	905·7	696·2	2·3	0·80	2·9	0·68	123·5	37·7	Sandstone and slate.
October, "	570	3,491	1,064	6·1	1·86	2,650	1,202	1,237·0	950·9	2·1	0·73	2·8	0·66	153·5	46·8	Sandstone and slate.
November, "	765	4,408	1,344	5·6	1·71	2,700	1,224	1,276·5	981·0	2·1	0·73	3·4	0·80	120·0	36·6	Sandstone.
December, "	798	4,410	1,344	5·5	1·68	5,775	2,609	1,002·0	770·2	5·7	1·98	4·4	1·08	156·0	47·7	"
January, 1871....	665	3,667	1,118	5·5	1·68	3,075	1,395	1,158·0	890·2	2·7	0·94	3·2	0·75	164·5	50·1	"
February, "	596	3,432	1,046	5·7	1·74	3,900	1,769	1,701·0	1,207·6	2·3	0·80	2·0	0·47	265·0	80·8	Sandstone and slate.
March, "	545	5,316	1,620	9·8	2·99	3,900	1,769	1,359·5	1,045·0	2·9	1·00	3·9	0·91	215·5	65·7	Sandstone and slate.
April, "	461	2,633	802	5·6	1·71	1,900	862	666·0	512·0	2·9	1·00	4·0	0·94	195·5	59·6	Sandstone and slate.
May, "	807	4,438	1,352	5·5	1·68	2,600	1,179	873·0	671·1	2·9	1·00	5·0	1·17	145·5	44·4	Conglomerate.
June, "	753	4,055	1,236	5·4	1·65	....	...	839·9	645·7	....	....	4·8	1·12	145·5	44·4	"
July, "	671	3,803	1,159	5·7	1·74	....	....	988·0	759·5	....	....	3·8	0·89	179·0	54·6	"
August, "	756	4,241	1,293	5·6	1·71	....	....	861·0	661·9	....	....	4·9	1·15	156·0	47·6	"
September, "	661	3,581	1,091	5·4	1·65	....	....	822·0	631·7	....	....	4·4	1·03	149·0	45·5	"
Total..............	8874	52,282	15,936	.	....	30,075	13,639	14,690·5	11,291·5	....	....	...	....	2298·5	699·1	
Average..........	....	....	....	5·9	1·80	....	....	....	....	2·7	0·94	3·7	0·87	163·8	49·9	

* This table represents machine-drilling at the south end only. Heading at bottom 8′ high by 16′ wide, = 128 square feet, or 11·2 square metres.

† Headings completed September 15th.

‡ This table represents the aggregate progress of the enlargement from working at several points.

TABLE 40.

MUSCONETCONG TUNNEL.—*Progress of Headings.*

The West Heading averaged 7·5 feet (2·3 m.) high (at centre) by 26 feet (7·9 m.) wide at floor of heading.
" East " " 7·0 " (2·1 m.) " " " " " " " " " "

1872.

MONTHS.	West Heading, No. 1. Progress. Feet.	Mtrs.	Average Area. Sq. ft.	Sq. m.	East Heading. Progress. Feet.	Mtrs.	Average Area. Sq. ft.	Sq. m.
January	....	....	....	....	...	.. .	....	....
February	....	....	....	....	..	....	....	....
March	....	....	....	....	....	....	....	....
April	....	....	....	....	....	....	....	....
May	....	....	....	....	....	....	....	....
June	....	....	....	....		....	....	....
July	....	....	....	....		....	....	....
August	....	....	....	....	103	....	....	....
September	....	....	....	....		31·4	240·9	22·4
October	....	....	....	....	39	11·9	346·9	32·2
November	17*	5·2	174·7	16·26	58	17·7	233·8	21·7
December	40	12·2	183·9	17·1	55	16·8	220·0	20·4
Total progress	57	17·4	....	....	255	77·8	....	....
Best month	40	12·2	....	....	58	17·7	....	....
Average monthly progress	....	....	....	....	....	....	....	....
Average area	....	....	....	....	....	....	....	....
Average progress attained during last six months of work	....	....	....	....	....	....	....	....

1873.

MONTHS.	West Heading, No. 1. Progress. Feet.	Mtrs.	Average Area. Sq. ft.	Sq. m.	East Heading. Progress. Feet.	Mtrs.	Average Area. Sq. ft.	Sq. m.
January	57	17·4	193·8	18·0	79	24·1	192·8	17·9
February	69	21·0	182·9	17·0	74	22·5	202·5	18·8
March	95	29·0	201·1	18·65	96	29·2	200·9	18·6
April	41	12·5	291·4	27·0	107	32·6	227·4	21·1
May	14†	4·3	300·5	27·9	84	25·6	201·5	18·7
June	....	....	....	....	118	36·0	173·4	16·1
July	....	....	....	....	85	25·9	162·8	15·1
August	....	....	....	....	90	27·4	178·9	16·6
September	....	....	....	....	79	24·1	177·7	16·5
October	.. .	....	....	....	70	21·3	181·4	16·8
November	....	....	....	....	82	25·0	176·6	16·4
December	7‡	2·1	315·1	29·3	100	30·5	185·3	17·2
Total progress	283	86·3	....	....	1064	324·2	....	. ..
Best month	95	29·0	....	....	118	36·0	....	....
Average monthly progress	....	....	....	....	88·7	27·0	....	....
Average area	....	....	....	....	....	....	188·5	17·5
Average progress attained during last six months of work	....	....	....	....	....	....	....	....

1874.

MONTHS.	West Heading, No. 1. Progress. Feet.	Mtrs.	Average Area. Sq. ft.	Sq. m.	East Heading. Progress. Feet.	Mtrs.	Average Area. Sq. ft.	Sq. m.
January	49	14·9	348·3	32·3	113	34·5	182·1	16·9
February	53	16·1	415·7	38·6	123	37·5	191·7	17·8
March	22	6·7	356·6	33·1	114	34·8	181·5	16·9
April	36	11·0	363·9	33·8	56‖	17·1	209·4	19·5
May	83	25·3	280·1	26·0	83‖	25·3	165·7	15·4
June	125	38·1	209·7	19·4	94‖	28·7	160·6	14·9
July	144	43·9	216·1	20·0	114	34·8	208·4	19·4
August	134	40·8	178·8	16·5	115	35·1	158·2	14·7
September	144	43·9	183·9	17·1	108	32·9	170·5	15·8
October	124	37·8	184·5	17·2	125	38·1	187·8	17·4
November	141	43·0	193·6	18·0	107	32·6	164·9	15·3
December	77§	23·5	191·2	17·8	65§	19·8	167·5	15·6
Total progress	1132	345·0	....	....	1217	371·2	....	....
Best month	144	43·9	....	....	125	38·1	....	....
Average monthly progress	94·3	28·75	....	...	101·4	30·93	....	....
Average area	....	....	260·2	24·2	....	....	179·0	16·6
Average progress attained during last six months of work	140·1	42·7	....	....	116·5	35·5	....	....

* Begun November 13, 1872. † Work stopped May 7, 1873. ‡ This seven feet was work at odd times from May 7, 1873, to January 1, 1874.
§ Headings met December 15, 1874. ‖ Omitted in average on account of boiler detentions.

TABLE 41.

MUSCONETCONG TUNNEL.—*Progress of Enlargements.*

The West Heading enlargement averaged 12·0 feet high by 26 feet wide. The East Heading enlargement averaged 12·5 feet high by 26 feet wide.

MONTHS.	1873. West Heading, No. 1—Enlargement. Feet.	Metres.	1873. East Heading—Enlargement. Feet.	Metres.	1874. West Heading No. 1—Enlargement. Feet.	Metres.	1874. East Heading—Enlargement. Feet.	Metres.	1875. West Heading No. 1—Enlargement. Feet.	Metres.	1875. East Heading—Enlargement. Feet.	Metres.
January	....	....	....	....	70	21·3	103	31·4	117†	35·7	116†	35·4
February	....	....	64	19·5	72	21·9	106	32·3	198	60·4	185	56·4
March	....	....	47*	14·3	66	20·1	86	26·2	196	59·7	198	60·4
April	....	. ..	....	....	56	17·1	72	21·9	20‡	6·1	56§	17·1
May	....	....	55	16·8	26	7·9	90	27·4	....	....	....	....
June	....	....	52	15·8	87	26·5	96	29·3	....	....	....	....
July	....	....	69	21·0	88	26·8	108	32·9	....	....	....	....
August	....	....	66	20·1	105	32·0	110	33·5	....	....	....	....
September	....	....	84	25·6	110	33·5	113	34·4	....	....	....	....
October	....	....	102	31·1	130	39·7	115	35·1	....	....	....	....
November	....	....	93	28·3	122	37·2	81	24·7	....	....	....	....
December	....	....	98	29·9	109	33·2	71	21·6	....	....	....	....
Total	....	....	730	222·3	1041	317·2	1151	350·7	531	161·9	555	169·3
Best month	....	....	102	31·1	130	39·7	115	35·1	198	60·4	198	60·4
Average monthly progress	....	....	....	....	86·75	26·4	96	29·2	....	....	....	....

* Stopped work from March 15 to May 3, 1873. † Work stopped from January 20 to 28. ‡ Worked three days in April, 1875. § Met west enlargement April 10, 1875.

HOOSAC TUNNEL.—*Progress of Headings.*

(This Table is for the period after the State of Massachusetts took possession of the work. There are no records attainable of progress under the Haupt contracts preceding the State management. See Plate IV.)

TABLE 42.

East Heading.

	1854–62.		1864.		1865.		1866.		1867.		1868.		1869.		1870.		1871.		1872.		1873.	
	Feet.	Mtrs.	Feet.	Mtrs.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.
January	....	....	....	....	....	....	54·5	16·60	60	18·29	....	....	....	....	123	37·49	138	42·2	133	40·6	....	....
February	....	....	....	..	...	....	47·0	14·32	55	16·76	....	....	....	....	109	33·23	128	39·0	134	40·9	....	....
March	....	....	....	....	29·0[2]	8·84	63·0	19·21	91	27·74	....	....	....[4]	....	110	33·54	153	46·7	120	36·6	....	....
April	....	....	....	....	52·0	15·84	61·5	18·75	83	25·29	....	....	110	33·54	121	36·9	120	36·6	131	39·9	....	....
May	....	....	....	....	55·0	16·75	50·5	15·39	87	26·51	....	....	135	41·15	135	41·15	150	45·8	123	37·5	....	....
June	....	....	....	....	55·0	16·75	26·5[3]	8·08	102	31·09	....	....	157	47·85	142	43·4	157	47·9	136	41·5	....	....
July	....	....	....	....	61·5	18·94	48·0	14·62	131	39·92	....	....	147	44·80	123	37·49	167	50·9	129	39·3	....	....
August	....	....	....	...	69·5	21·19	54·5	16·60	123	37·49	....	....	130	39·62	150	45·71	133	40·6	138	42·2	....	....
September	....	....	....	....	54·5	16·60	38·5	11·73	111	33·84	....	....	135	41·14	126	38·40	164	50·0	112	34·2	....	....
October	...	....	....	....	63·5	19·36	36·5	11·13	117	35·66	....	....	132	40·23	127	38·71	161	49·1	125	38·1	....	....
November	....	....	....	....	66·0	20·12	42·0	12·80	126	38·40	....	....	147	44·80	133	40·54	161	49·1	145	44·3	....	....
December	....	....	....	....	44·5	13·55	48·0	14·62	101	30·78	....	....	146	44·50	115	35·06	111	33·9	68[5]	20·7	....	....
Totals	2399[1]	731·2	....	....	550·5	167·8	570·5	173·9	1187	361·8	....	....	1239	377·8	1514	461·6	1748	531·3	1495	455·7	...	....
Best month	....	...	....	....	69·5	21·19	63·0	19·21	131	39·92	....	....	157	47·85	150	45·71	167·0	50·9	145	44·3	....	....
Average, monthly	....	....	....	....	55·05	16·78	47·54	14·49	98·92	30·15	....	....	137·66	41·98	126·17	38·46	145·25	44·28	124·58	37·98	....	....

TABLE 43.

West Heading.[6]

	1854–62.		1864.		1865.		1866.		1867.		1868.		1869.		1870.		1871.		1872.		1873.	
	Feet.	Mtrs.	Feet.	Mtrs.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.
January	....	....	..	....	16	4·87	43·0	13·10	..[11]	....	33	10·06	....	....	79	24·08	112	34·2	136	41·5	153	46·7
February	....	....	4[7]	1·22	10[10]	3·05	43·5	13·25	..	....	35	10·67	....	....	63	19·21	101	30·8	128	39·0	137	41·9
March	....	....			..	....	38·5	11·73	..	....	34	10·4	....	....	105	32·01	104	31·7	140	42·8	162	49·4
April	....	....	13	3·96	..	....	38·0	11·58	..	....	24	7·32	....	....	100	30·48	109	33·2	140	42·8	136	41·5
May	....	....			16	4·87	59·0	18·18	..	....	26	7·93	....	....	79	24·08	130	39·6	142	43·4	120	36·6
June	....	....	19	5·79	33	10·06	64·0	19·51	20	6·1	21[13]	6·41	....	....	80	24·38	114	34·8	142	43·4	126	38·4
July	.. .	....	12[8]	3·66	33	10·06	64·5	19·66	31[12]	9·45	47	14·32	69[16]	21·04	97	29·57	110	33·5	145	44·3	137	41·9
August	....	....	12	3·66	37	11·28	61·0	18·79	39	11·88	44[14]	13·40	58	17·68	112	34·14	130	39·6	150	45·8	93	28·3
September	....	....	18	5·48	37	11·28	74·0	22·56	49	14·93	51[15]	15·54	76	23·17	103	31·39	106	32·3	85	25·9	132	40·3
October	...	....	16	4·87	57	17·37	58·5	18·03	54	16·46	..	....	29	8·84	125	38·10	101	30·8	140	42·8	140	42·6
November	....	....	2[9]	·61	47	14·32	38·0	11·58	33	10·06	..	....	115	35·05	130	39·62	131	39·9	136	41·5	96[17]	29·3
December	....	....	..	....	45	13·71	4·0	1·22	22	6·71	..	....	102	31·09	130	39·62	132	40·3	132	40·3	....	....
Totals	....	....	96	29·3	331	100·8	586·0	178·6	248	75·7	315	96·0	440	137·0	1203	366·7	1380	420·6	1616	492·6	1432	436·5
Best month	....	....	19	5·79	57	17·37	74	22·56	54·0	16·4	51·0	15·54	115	35·05	130	39·62	132	40·3	150	45·8	162	49·4
Average, monthly	....	....	12·0	3·66	33·1	10·08	48·83	14·88	35·43	10·81	35·0	10·67	74·83	22·83	100·25	30·56	115·0	35·05	134·67	41·05	130·18	39·68

TABLE 44.

Central Shaft, Heading driven East.

January	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	13	4·0	87	26·5	....	....
February	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	20	6·1	93	28·3	....	....
March	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	40	12·3	100	30·5	....	....
April	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	waiting	....	98	29·0	....	....
May	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	for	....	93	28·3	....	....
June	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	pumps.	....	102	31·1	....	....
July	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	5	1·5	109	33·2	....	....
August	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	31	9·4	109	33·2	....	....
September	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	27	8·2	105	32·0	....	....
October	....	....	....	....	....	....	....	....	....	....	....	....	....	....	8·5[18]	1·07	0[19]	....	132	40·3	....	....
November	....	....	....	....	....	....	....	....	....	....	....	....	....	....	30·5	9·31	54[20]	16·5	148	45·2	....	....
December	....	....	....	....	....	....	....	....	....	....	....	....	....	....	10·0	3·05	87	26·5	50[21]	45·8	....	....
Totals	....	....	....	....	....	....	....	....	....	....	....	....	....	....	44·0	13·5	277	84·5	1226	373·7	....	....
Best month	....	....	....	....	....	....	....	....	....	....	....	....	....	....	30·5	9·31	87	26·5	148	45·2	....	....
Average, monthly	....	....	....	....	....	....	....	....	....	....	....	....	....	....	14·66	4·5	84·63	10·56	102·17	31·14	....	....

TABLE 45.

Central Shaft, Heading driven West.

January	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	32	9·8	64	19·5	144[26]	44·0
February	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	39	12·0	21	6·4	140	42·8
March	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	44[22]	13·5	..[23]	....	155	47·3
April	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	..	....	..	....	163	49·7
May	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	..	....	14[24]	4·3	155	47·3
June	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	..	....	..	....	181	39·9
July	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	..	....	..	....	151	46·1
August	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	..	....	..	....	158	48·2
September	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	..	....	..	....	184	56·1
October	....	....	....	....	....	....	....	....	....	....	....	....	....	....	9·5	2·90	..	...	..	...	170	51·8
November	....	....	....	....	....	....	....	....	....	....	....	....	....	....	45·5	13·86	..	....	..	....	146[27]	44·6
December	....	....	....	....	....	....	....	....	....	....	....	....	....	....	16·0	4·87	38	11·7	20[25]	6·1	....	....
Totals	....	....	....	....	....	....	....	....	....	....	....	....	....	....	71·0	21·6	153	46·7	119	36·3	1697	517·3
Best month	....	....	....	....	....	....	....	....	....	....	....	....	....	....	45·5	13·86	44	13·5	64·0	19·5	184	56·1
Average, monthly	....	....	....	....	....	....	....	....	....	....	....	....	....	....	23·66	7·2	38·25	11·67	20·75	9·075	154·27	47·03

[1] The east heading was taken up at a point 2399′ (731 m.) from the mouth, to which point it had been driven under the previous contracts.

[2] This 29′ is work of half month. During 1864, bottom of old tunnel was lowered, and by December 1st old bench was reached; this was taken out by March 15th, 1865, and the new heading was then started at the bottom instead of at top as before. The heading from March, 1865, to July 1st, 1866, was driven 6½′ high by 14′ to 15′ wide. From July 1st, 1866, to March 1st, 1867, 8′ by 17′; from March 1st, 1867, to October 1st, 18 7, 8′ by 18′, and from that date to the end, about 8′ to 8½′ high by 24′ wide. The west heading averaged about the same dimensions.

[3] In June, 1866, the change from hand to machine drilling was made.

[4] Work was begun by the Shanly Brothers at the east heading, March 29th, 1869, at a point 5283′ from the east portal.

[5] Heading met that driven east from central shaft, December 12th, 1872.

[6] This heading was started east from the west shaft. On July 7th, 1868, the heading driven west from west shaft met adit driven east from west open cut. No tables given of heading west of west shaft, as progress was very irregular. (See profile, plate 4.)

[7] Work begun February 6th, 1864, at a point 32 feet east of the west shaft, which had been reached by Haupt & Co., who sunk the shaft during their contract.

[8] Work suspended from July 23d, 1864, to August 1st, 1864.

[9] Work suspended from November 12th, 1864, to January 1st, 1865.

[10] No work from February 15th, 1865, until May 15th, 1865.

[11] Work suspended from January 1st, 1867, until June 14th, 1867, due to water.

[12] Raised, during July and August, 1867, the heading from bottom to top of tunnel.

[13] Machine drills introduced during June, 1868

[14] Nitro-glycerine permanently introduced during August, 1868.

[15] Work discontinued until July, 1869.

[16] Work begun by Shanly Brothers, July 2d, 1869, at a point 4058 feet from the west portal.

[17] Heading met the one driven west from central shaft November 27th, 1873.

[18] Central shaft headings begun by Shanly Brothers, October 25th, 1870, with hand labor.

[19] Putting in machine-drill carriage.

[20] Part of month only.

[21] See note 5 above.

[22] Interrupted, and detained to December by water and lack of pumps.

[23] Force at work taking out bottom so as to push heading at bottom.

[24] Only a few days' work when flooded.

[25] Only a few days' work in December.

[26] Machine-drills started.

[27] See note 17 above.

TABLE 46.

THE SUTRO TUNNEL.*—*Rate of Progress.*

(See p. 348 for drilling table, etc.)

MONTHS.	1869.		1870.		1871.		1872.		1873.	
	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.
January	....	....	201	61·3	53	16·1	47	14·3	90	27·5
February	....	....	136	41·4	39	11·9	72	22·1	81	24·8
March	...	....	95	29·0	53	16·1	29	8·8	121	36·9
April	....	....	110	33·5	35	10·6	45	13·7	116	35·3
May	....	....	135	41·1	116	35·3	45	13·7	114	34·7
June	....	....	157	47·7	135	41·1	40	12·2	85	26·0
July	....	....	116	35·3	90	30·2	40	12·2	109	33·2
August	....	...	82	25·1	98	29·9	117	35·6	118	35·9
September	....	....	126	38·4	80	24·5	105	32·0	123	37·5
October	....	....	19	5·8	53	16·1	91	27·8	105	32·0
November	254†	77·4	48	14·6	61	18·6	91	27·8	{ 655‡ 73 }	22·3
December	206†	62·8	65	19·8	93	28·4	93	28·4	129	39·3
Total	460	140·2	1290	393·0	915	278·8	815	248·6	1264§	385·4
Best month	254	77·4	201	61·3	135	41·1	117	35·6	129	39·3
Average monthly progress	230	70·1	107·5	32·8	76·2	23·2	67·9	20·7	105·3	32·1

MONTHS.	1874.		1875.		1876.		1877.		1878.	
	Feet.	Metres.	Feet.	Metres.	Feet.	Metres	Feet.	Metres.	Feet.	Metres.
January	134	40 8	350	106.6	300	91.4	388	118.3	237	72.4
February	98	29 9	289	88 1	308	93.8	361	109.9	216	65.9
March	99	30.2	314	95.6	360	109.6	207	63.1	244	74.5
April	136	41.4	239	72.9	300	91.4	225	68.6	238	72.6
May	151	46.8	309	94.1	263	80.2	277	84.5	231	70.5
June	194	59.2	358‖	109.0	300	91.4	334	101.8	198	60.4
July	208	63.4	358‖	109.0	201	61.3	342	104.2	239	72.9
August	300	91.4	370‖	112 6	346	105.4	279	85.0	279	85.2
September	310	94.4	326	99.3	329	100.2	116	35.4	....	....
October	360	109.6	285	86.9	321	97.8	141	43.0	....	....
November	270	82.3	335	102 0	315	95.9	221	67.4	....	....
December	417	127.2	195	59.5	327	99.6	239	72.8**	...	....
Total	2680	816.6	3728	1136.6	3670	1118.0	3130	954.0	1882	574.4
Best month	417	127.2	350¶	106.6	360	109.6	388	118.3	279	85.2
Average monthly progress	223.3	68.1	310.7¶	94 7	306	93.2	260.9	79.5	235.3	71.8

* Area of tunnel driven as follows: November, 1869, to April, 1870, inclusive, 14′ × 16′; May, 1870, to March, 1874, 8′ × 8′; April, 1874 to October, 1874, 8′ × 14′; November, 1874, to end of tunnel, 8′ × 10′ = 80 square feet, or 7.4 square metres. Hand labor from the beginning up to March, 1874, when two machine-drills started; subsequently the number was increased.

† November progress includes from October 19th to December 3d; December progress from December 3d to 31st.

‡ This 655 feet is total length of drifts run from bottom of shaft No. 1 either way; they were begun August 14th, 1873, and connected with the main heading October 27th, 1873.

§ Does not include 655′ drift work.

‖ These three months embrace 360 feet of drift work from shaft No. 2, which had fallen in and had to be re-excavated.

¶ Owing to reasons in note above, June, July, and August are not considered.

** On January 1st, 1878, the total number of feet driven = 18,607; total length of tunnel to proposed point of intersection with Savage Mine = 20,351; remaining distance to be driven = 1744. The progress for September and October, 1877, was rendered short by the bad ground encountered. The heading met the drift from the Savage Mine, July 8, 1878, at a total distance of 20,018 feet from the mouth of the tunnel.

TABLE 46½. (*Continued.*)

THE SUTRO TUNNEL.—*Analysis of Work in Main Tunnel, and in North and South Laterals.*

Month Ending.	Progress per month (feet).	Temperature of Air (Deg.).		Temperature of water at mouth (Deg.).	Temperature of rock at heading (Deg.).	Holes.			Powder consumed (pounds).	Exploders consumed (number).	Rock extracted (car loads).	Drills sharpened.	Number of men employed in tunnel.	Flow of water, miners' inches.	Nature of Ground.	Character of Rock.
		At mouth.	At heading.			Drilled.	Aggregate depth.	Average depth.								
1875.																
Jany ...	350	44	82	....	....	....	......	....	....	....	....	....	68	20	Favorable, 10 inch seam, with water............	Trachyte.
Feby...	289	40	83	....	...	....	......	....	....	....	....	....	75	49	Very wet, sudden influx of water.	Trachyte.
March..	314	53	81	....	.. .	....	......	....	....	....	....	....	74	60	Hard, dry. tapping water from Shaft No. 2........	....
April ..	239	63	81	....	....	....	......	....	....	....	....	....	80	57	Ground softened by water.	....
May....	309	71	80	75	....	1862	10637	5.71	5174	2229	1747	....	78	68	....	Conglomerate of greenstone, trachyte.
June. ..	358	73	80	....	....	1730	10660	6.08	3866	1894	2275	....	79	84	Very wet....................	Conglomerate of greenstone, trachyte, and porphyry.
July....	358	76	80	76	....	1285	8626	6.60	3547	1407	2323	....	70	51	Very hard, dry............	Andesite and Comstock porphyry.
August.	370	80	83	75	....	1166	8052	6.90	2636	1244	2586	1411	69	44	Good, soft and very soft....	Porphyry, clay and quartz.
Sept....	326	81	85	76	....	1094	8071	7.39	2439	1183	2337	1533	70	44	Fair, then soft and treacherous...	Porphyry and quartz.
Oct.....	285	62	84	76	....	951	6895	6.93	2286	1087	1960	1417	68	40	Soft, then hard and fair....	Green porphyry.
Nov....	335	46	86	74	....	1230	9687	7.80	4061	1604	1842	3168	69	40	Hard	Porphyritic slate, quartz, quartzite and calcspar.
Dec.....	195	54	86	74	....	564	4323	6.95	1316	593	1628	1071	66	52	Very wet....................	Porphyritic slate, greenstone, quartzite, quartz, clay.
1876.																
Jany....	300	43	83	75	....	849	6367	7.20	1947	905	2109	2476	68	57	Hard, wet..................	Andesite, greenstone.
Feby ...	308	54	86	75	....	1009	7982	7.95	3809	1236	2060	1998	68	56	Hard.......................	Clay, porphyry, bowlders, greenstone.
March..	360	53	83	74	....	1204	9878	8.20	4447	1397	2193	2426	68	49	....	Greenstone, with clay seams.
April...	300	61	85	77	....	912	7149	8.60	3006	1124	2217	1690	70	71	Hard, wet..................	Greenstone and Comstock porphyry.
May.....	263	71	87	76	....	1088	8335	7.62	4288	1409	1662	2635	64	134	Very hard..................	Comstock porphyry.
June ...	300	75	85	76	....	1223	9791	7.95	5395	1650	2032	3109	72	144	Hard, dry and fair, little wet......................	Porphyry, propylite.
July	201	79	86	78	.. .	689	4678	6.57	2210	997	1848	1552	59	162	....	Decomposed porphry with clay quartz.
August .	346	80	84	77	....	1188	9651	8.11	3848	1447	2273	2735	59	179	Very hard—soft—medium..	Limestone, greenstone, porphyry.
Sept....	329	73	85	78	....	1039	8715	8.38	3334	1142	2123	3217	65	215	Soft........................	Propylite and vein matter.
Oct.....	321	63	86	78	....	1113	8235	7.40	3868	1416	2077	3754	66	250	First 91 feet soft, then very hard....................	Propylite, with quartz stringers.
Nov	315	55	87	78	....	1016	8358	8.22	3549	1351	1967	3761	65	187	Fair........................	Propylite and 4 ft. quartz lode.
Dec.....	327	49	89	77	....	1099	8142	7.50	3380	1295	2016	1937	64	134	Medium, and very soft.....	Propylite.
1877.																
Jany ...	388	48	88	77	....	1321	10698	8.09	5363	1603	2196	2330	63	113	Favorable..................	Propylite.
Feby. ..	361	51	88	77	....	1363	10525	7.69	5073	1584	1927	2354	63	98	Hard, with few seams of clay....................	Propylite.
March..	207	63	89	77	....	792	5660	7.14	2005	841	1563	1845	64	115	First 170 feet close timbering....................	Decomposed porphyry, with clay seams.
April. ..	225	47	90	78	....	911	6531	7.18	2624	1025	1394	2812	56	104	First half close timbering—towards end very hard..	Black propylitic vein matter, second half andesite.
May....	277	64	89	77	....	996	8060	8.02	4198	1161	1654	2784	47	83	First hard, then good, but required timbering.....	Andesite; last 17 days bird's-eye porphyry.
June ...	334	76	90	75	....	1022	8095	7.92	3485	1043	1892	1337	47	82	Very favorable ground.....	Green porphyry, partly decomposed, and some vein matter.
July....	342	80	90	78	....	1016	7847	7.72	3041	1044	2011	1458	47	78	Fair, 104 feet timbering....	Decomposed bird's-eye porphyry.
August.	279	87	89	77	....	780	6254	7.98	2184	811	1936	1854	49	69	Fair, partly timbered—last week swelling ground, heavy timbering........	Decomposed porphyry, with clay seams and quartz.
Sept....	116	79	90	75	....	156	953	4.44	186	118	1573	321	52	90	Swelling ground, very heavy timbering; since 14th Sept. small drift driven ahead and enlarged.....	Decomposed porphyry, with clay seams and pockets of good quartz.

TABLE 46½. (*Continued.*)

Month Ending.	Progress per month (feet).	Temperature of Air (Deg.).		Temperature of water at mouth (Deg.).	Temperature of rock at heading (Deg.).	Holes.			Powder consumed (pounds).	Exploders consumed (number).	Rock extracted (car loads).	Drills sharpened.	Number of men employed in tunnel.	Flow of water, miners' inches.	Nature of Ground.	Character of Rock.
		At mouth.	At heading.			Drilled.	Aggregate depth.	Average depth.								
1877.																
Oct.	141	69	90	73	....	397	803	4.97	681	373	1707	683	63	53	....	....
Nov	221	49	94	72	100	525	3740	7.10	947	517	1874	774	62	58	Close timbering	Porphyry, with many clay and quartz seams.
Dec.	239	37	94	71	....	583	4298	7.30	1220	610	1958	1087	52	63	Timbering	Decomposed porphyry, clay and quartz seams, greenstone and andesite.
1878.																
Jany.	237	46	96	71	103	462	3330	7.20	828	494	2104	761	54	73	Close timbering, little water	
Feby	216	47	95	70	109	555	4082	7.30	1025	596	1835	873	56	89		Decomposed greenstone, many clay and quartz seams.
March	244	55	98	70	110	737	5335	7.20	2578	897	1750	1324	57	89	Close timbering, then hard.	First 115 feet decomposed porphyry, then black andesite.
April	238	60	101	70	109	656	4556	7.00	1560	668	1714	979	58	89	Timbering, last 70 feet hard.	Porphyry, clay and quartz.
May	231	65	100	70	110	723	5660	7.40	2077	780	1653	934	69	89	Mostly timbering	Porphyry, clay and quartz, andesite.
June	198	91	101	73	110	606	4802	7.50	1622	635	1296	1657	70	89	....	Vein porphyry; last 50 feet black andesite.
July	239	84	101	73	110	670	4776	8.10	2398	760	1560	1411	71	89	....	Quartz containing silver and gold, andesite and porphyry.
August	279	81	96	68	108	755	7230	9.30	2301	726	1796	1516	73	89	Partly timbering	Vein matter.

NORTH LATERAL TUNNEL.

Month Ending.	Progress per month (feet).	Air at mouth.	Air at heading.	Water at mouth.	Rock at heading.	Drilled.	Aggregate depth.	Average depth.	Powder consumed.	Exploders consumed.	Rock extracted.	Drills sharpened.	Number of men.	Flow of water.	Nature of Ground.	Character of Rock.
1879.																
August	313	79	97	118	....	691	5122	5.70	2083	727	1236	1591	56	......	Hard—very hard—good	Porphyry, andesite, vein porphyry with clay and quartz seams.
Sept.	201	70	94	112	104	580	4335	8.00	1787	579	1284	1859	47	......	Hard—very hard—good—hard	Porphry, andesite, vein porphyry, andesite.
Oct	310	59	85	115	79	229	1362	6.70	875	247	595	243	40	......	Very hard, good, soft, timbering	Porphyry, vein porphyry.
Nov.	301	41	90	117	109	655	4670	7.00	1061	589	1290	906	46	169	Soft, timbering, wet, then good	Vein porphyry, propylite.
Dec.	302	36	90	112	....	830	5780	7.00	1440	858	1765	2127	52	169	Good	Porphyry, quartz and clay, propylite, andesite.
1880.																
Jany.	429	36	90	111	105	944	7177	....	2294	1080	1981	1320	50	175	Good, timbering	Vein porphyry.
Feby	308	55	93	115	....	896	6987	7.40	3126	1050	1541	1385	54	176	" "	" "
March	283	45	91	114	....	577	4590	8.00	1525	645	1392	2468	57	185	" "	" "
April	291	67	89	115	....	703	5440	8.00	2155	825	1782	2663	44	217	" "	" "
May	321	66	90	116	....	768	6143	8.00	1710	839	2011	1624	52	208	" "	" "
June	404	66	89	118	....	1222	9812	8.00	4163	1282	1925	1893	56	243	....	Vein porphyry, with clay and quartz seams.
July	304	87	92	121	118	928	7424	8.00	3248	979	1529	3105	48	214	Good	Vein porphyry, with clay and quartz seams.
August	243	81	100	116	115	777	......	7.75	2495	940	1571	2114	49	214	....	Vein porphyry, with clay and quartz seams.
Sept. 1 to Oct. 4.	308	77	99	116	118	981	7708	8.00	3476	1115	1606	2085	44	223	....	Vein porphyry, with clay and quartz seams.

SOUTH LATERAL TUNNEL.

Month Ending.	Progress per month (feet).	Air at mouth.	Air at heading.	Water at mouth.	Rock at heading.	Drilled.	Aggregate depth.	Average depth.	Powder consumed.	Exploders consumed.	Rock extracted.	Drills sharpened.	Number of men.	Flow of water.	Nature of Ground.	Character of Rock.
1878.																
Sept.	276	59	95	71	106	720	5365	6.60	1778	807	1736	1306	53	74	Hard, first 8 days hand labor.	Porphyry, and 3 ft. quartz vein.
Oct.	309	64	99	71	111	817	8050	9.80	2766	959	1949	1828	53	74	Good	Porphyry.
Nov	296	53	99	70	110	817	7901	9.60	2953	929	1825	1664	53	74	Soft	Porphyry, with clay and quartz.
Dec	287	45	102	70	118	804	7298	9.30	3409	850	1834	1869	67	74	Soft	First 15 days porphyry and andesite, then vein porphyry.
1879.																
Jany.	218	51	103	70	115	568	4876	8.60	1989	683	1428	1459	66	74	Soft	Vein porphyry.
At different periods.	108	......	......	......	......	......	......	......	......	......	......	......	......	......	....	....
Nov	252	41	94	117	....	736	4487	6.00	1635	801	1191	850	40	169	Timbered, wet	Vein porph., and 8 in. quartz vein.
Dec. (26)	184	36	97	112	...	458	2778	5.80	689	457	1166	998	52	169	Soft, swelling	Vein porphyry.
1880.																
Jany.	236	36	95	111	117	532	3808	6.50	1341	626	1679	928	50	175	Fair, 20 feet swelling	Vein porphyry.
Feby., 11 days	66	......	100	....	....	117	1058	6.20	306	174	546	335	56	......	Good	" "
May (25½)	315	66	91	116	....	781	5310	6.50	2088	816	1934	876	51	208	First swelling, then very favorable, progress in one week 148 feet	One half vein porphyry, with clay and quartz, one half propylite.
June (25)	209	66	92	118	....	441	3229	7.00	651	472	1748	874	52	243	Swelling, timbering	Vein porphyry.
July (18½)	120	87	105	121	122	332	2100	7.50	566	316	1071	436	61	214	" "	" "
Aug. (11)	59	......	97	...	....	194	1340	6.50	507	285	505	429	52	214	" "	" "
Sept. (26½)	242	77	98	116	123	607	4251	7.00	1205	575	1629	337	56	223	" "	" "
Oct.	304	57	97	117	115	799	5521	7.00	1856	833	2051	999	55	211	Swelling	Porphyry and andesite bowlders, imbedded in clay.
Nov	216	50	100	118	121	438	3030	6.80	1237	489	1695	1358	54	212	Swelling, heaviest ground encountered	Porphyry and andesite bowlders, imbedded in clay.

TABLE 47.

THE ROTHSCHÖNBERG ADIT AT FREIBERG.—*Rate of Progress per Year by Hand Labor with Black Powder.** (*Before Mezger's Contract.*)

	MOUTH.		FIRST AIR-SHAFT.				SECOND AIR-SHAFT.				THIRD AIR-SHAFT.				FOURTH AIR-SHAFT.			
			North-east.		South-west.		North-east.		South-west.		North-east.		South-west.		North-east.		South-west.	
	Feet.	Mtrs.	Feet.	Mtrs.	Feet.	Mtrs.	Feet.	Mtrs.	Feet.	Mtrs.	Feet.	Mtrs.	Feet.	Mtrs.	Feet.	Mtrs.	Feet.	Mtrs.
1847	689·0	210	124·6	38	....	....	....	....	....	....	....	....	....	....	....	....	....	....
1848	282·4	86	104·9	32	85·3	26	....	....	....	....	....	....	....	....	39·3	12	39·3	12
1849	354·3	108	127·9	39	39·3	12	6·6	2	....	....	....	....	....	....	223·1	68	91·9	28
1850	347·7	106	279·1	85	....	....	176·2	54	131·2	40	....	....	....	....	236·2	72	72·2	22
1851	364·1	111	32·8	10	....	....	334·7	102	269·1	82	....	....	....	....	124·6	38	91·9	28
1852	252·6	77	....	....	....	....	282·4	86	275·4	84	....	....	....	....	172·9	53	59·0	18
1853	279·1	85	....	....	....	....	285·7	87	328·1	104	....	....	....	....	226·4	69	196·9	60
1854	298·8	91	....	....	....	....	321·8	98	354·3	100	....	....	....	....	210·0	64	269·1	82
1855	262·5	80	....	....	150·9	48	246·0	75	167·3	108	....	....	....	....	216·6	60	183·8	56
1856	295·5	90	....	....	59·0	18	72·1	72	173·9	51	....	....	....	....	206·7	63	216·6	66
1857	318·5	97	....	....	13·1	4	229·7	70	....	....	....	....	....	....	272·1	83	118·0	36
1858	337·9	103	....	....	65·6	20	210·0	64	32·8	10	39·3	12	39·3	12	190·4	58	124·6	38
1859	331·3	101	....	....	282·4	86	91·9	28	....	....	177·2	54	150·9	46	127·9	39	131·2	40
1860	282·4	88	....	....	226·4	69	....	....	....	....	170·6	52	157·5	48	121·3	37	104·9	32
1861	286·0	88	....	....	262·5	80	....	....	....	....	210·0	64	196·9	60	157·5	48	196·9	60
1862	393·6	119	....	....	311·9	95	....	....	....	....	249·3	76	203·5	62	170·6	52	39·3	12
1863	183·8	56	....	....	360·8	110	....	....	....	....	311·9	95	337·9	103	144·3	44	32·8	10
1864	164·1	50	78·7	24	321·8	98	....	....	....	....	292·0	89	200·2	61	131·2	40	173·9	53
1865	....	....	....	....	249·3	76	....	....	....	....	170·6	52	203·5	62	150·9	46	157·5	48
1866	....	....	....	....	328·1	100	....	....	....	....	118·0	36	72·2	22	137·8	42	95·1	29
1867	....	....	....	....	308·7	94	....	....	....	....	....	....	....	....	216·6	66	101·7	31
1868	....	....	....	....	177·2	54	....	....	....	....	....	....	....	....	147·6	45	36·0	11
1869	....	....	....	....	....	....	....	....	167·3	51	....	....	....	....	173·9	53	3·3	1
1870	....	....	....	....	....	....	....	....	229·7	70	19·7	6	....	....	255·9	78	75·5	23
1871	....	....	....	....	6·6	2	....	....	239·5	73	236·2	72	36·1	11	....	....	203·4	62
1872	....	....	....	....	....	....	....	....	347·7	106	229·7	70	....	....	....	....	239·5	73
1873	....	....	....	....	....	....	....	....	118·1	26	108·2	33	....	....	....	....	62·3	10
Total	5722	1744	748	228	3255	992	2421	738	3002	915	2333	711	1598	487	4036	1230	3117	950
Best year	394	119	279	85	361	110	335	102	328	104	312	95	338	103	256	78	269	82
Average	318	97	124·7	38	191·5	58·3	220·1	67·1	230·9	70·4	179·5	54·7	159·8	48·7	173·5	53·5	119·9	36·5

	FIFTH AIR-SHAFT.				SIXTH AIR-SHAFT.				SEVENTH AIR-SHAFT.				AUXILIARY SHAFT.	
	North-east.		South-west.		North-east.		South-west.		North-east.		South-west.			
	Feet.	Mtrs.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.
1847	....	....	....	....	....	....	....	....	....	....	....	....	....	....
1848	....	....	....	....	....	....	....	....	....	....	....	....	....	....
1849	13·1	4	98·4	30	....	....	....	....	91·9	28	....	....	....	....
1850	26·2	8	177·2	54	....	....	....	....	124·6	38	....	....	....	....
1851	98·4	30	262·5	80	....	....	....	....	279·1	85	9·8	3	....	....
1852	59·0	18	213·3	65	....	....	....	....	200·0	61	....	....	....	....
1853	124·6	38	282·4	86	....	....	....	....	137·8	42	....	....	....	....
1854	137·8	42	318·5	97	....	....	....	....	275·8	84	....	....	....	....
1855	118·0	36	269·1	82	....	....	....	....	272·5	83	....	....	....	....
1856	249·3	76	210·0	64	....	....	....	....	252·6	77	....	....	....	....
1857	144·3	44	216·6	66	....	....	....	....	170·6	52	62·3	19	....	....
1858	98·4	30	111·5	34	....	....	....	....	26·2	8	13·1	4	....	....
1859	19·7	6	85·3	26	....	....	....	....	....	....	....	....	....	....
1860	78·6	24	216·6	66	....	....	....	....	....	....	....	....	....	....
1861	65·6	20	78·6	24	....	....	....	....	....	....	....	....	....	....
1862	85·3	26	137·8	42	....	....	....	....	127·9	39	131·2	40	....	....
1863	124·6	38	177·2	54	....	....	....	....	121·3	37	170·6	52	98·4	30
1864	170·6	52	190·4	58	....	....	....	....	59·0	18	75·5	23	52·5	16
1865	137·8	42	196·9	60	9·8	3	....	....	118·0	36	50·0	18	118·0	36
1866	59·0	18	111·5	34	42·6	13	45·9	14	131·2	40	101·7	31	91·9	28
1867	....	....	9·8	3	65·6	20	111·5	34	3·3	1	6·6	2	6·6	2
1868	78·6	24	229·7	70	144·3	44	190·4	58	19·7	6	....	....	13·2	4
1869	13·1	4	226·4	69	200·0	61	233·0	71	246·0	75	65·6	20	91·9	28
1870	59·0	18	173·9	53	68·9	21	200·0	61	255·9	78	124·6	38	95·2	29
1871	213·3	65	187·1	57	206·7	63	206·7	63	193·6	59	114·7	35	....	....
1872	203·4	62	216·6	56	259·2	79	344·4	105	206·7	63	179·5	55	....	....
1873	55·7	17	62·3	19	59·0	18	328·1	100	259·2	79	213·3	65	....	....
Total	2435	742	4426	1349	1036	322	1660	506	3573	1089	1329	405	568	173
Best year	249	76	318	97	259	79	344	105	275	84	213	65	118	36
Average	101·5	30·9	184·5	56·2	117·3	35·8	207·5	63·25	162·4	49·5	94·9	28·9	71	21·6

* This table is only given in contrast to that of the Sutro Tunnel, where it will be seen that machine-drills and dynamite have afforded an average progress *per month* greater than that obtained at Rothschönberg *per year*. (See p. 375.)

TABLE 48.

The Mont Cenis Tunnel.*—*Progress of Headings.*

Months.	1861.		1861.		1862.		1862.		1863.		1863.		1864.		1864.		1865.		1865.	
	Bardonnèche.	Modane.	Bardonnèche.	Modane.	Bardonnèche.	Modane.	Bardonnèche.	Modane.	Bardonnèche.	Modane.	Bardonnèche.	Modane.	Bardonnèche.	Modane.	Bardonnèche.	Modane.	Bardonnèche.	Modane.	Bardonnèche.	Modane.
	Feet.		Metres.		Feet.		Metres.		Feet.		Metres.		Feet.		Metres.		Feet.		Metres.	
January	....	....	....	....	106·96	....	32·60	....	56·70	14·53	17·30	4·43	142·69	78·91	43·50	24·05	214·25	126·15	65·30	38·45
February	....	....	....	....	93·34	....	28·45	....	104·66	75·76	31·90	23·09	131·57	141·58	40·10	43·15	185·70	182·59	56·60	55·65
March	31·83	....	19·70	....	102·64	....	31·65	....	80·06	110·67	24·40	33·76	134·19	141·42	40·90	43·10	221·14	177·17	67·40	54·00
April	57·42	....	17·50	....	87·27	....	26·60	....	96·46	103·09	29·40	31·42	157·82	168·48	48·10	51·35	196·86	173·73	60·00	52·95
May		....		....	112·54	....	34·30	....	114·18	127·30	34·80	38·80	142·07	80·50	43·30	24·55	205·55	299·56	62·65	91·30
June	468·53	....	142·80	....	106·63	....	52·50	....	110·73	127·46	33·75	38·85	161·43	86·95	49·20	26·50	213·82	162·43	65·15	49·50
July		....		....	124·74	...	38·02	....	153·71	106·96	46·85	32·60	190·48	153·55	60·80	46·80	242·96	52·82	74·05	16·10
August		...		....	113·29	....	34·58	....	189·11	83·83	42·40	25·55	185·70	99·91	56·60	30·45	236·06	44·95	71·95	18·70
September		....		....	109·09	....	33·25	....	138·79	92·85	42·30	28·30	187·35	147·81	57·10	45·05	226·06	63·98	68·90	19·50
October	468·53	....	142·80	....	114·88	...	35·00	....	145·35	118·52	44·30	34·60	202·60	166·67	61·75	50·80	225·93	62·00	68·50	19·20
November		....		....	98·43	....	30·00	....	145·02	111·88	44·20	34·15	196·04	129·27	59·75	39·40	185·38	67·92	56·50	20·70
December		....		....	108·60	...	33·10	....	108·93	162·41	33·20	49·55	197·18	134·06	60·10	40·85	142·24	89·73	43·30	27·35
Total { One end	557·8	....	170·0	...	1278·5	....	390·0	...	1303·7	1230·26	424·8	375·1	2038·2	1529·1	621·20	466·05	2495·95	1503·0	761·30	458·40
Total { Both ends	557·8		170·0		1278·5		390·0		2623·96		799·9		3567·3		1087·25		3998·95		1218·7	
Daily Progress { One end	1·57	..	0·48	....	3·41	....	1·04	....	3·84	3·38	1·17	1·03	5·58	4·17	1·70	1·27	6·89	3·705	2·10	1·25
Daily Progress { Both ends	1·57		0·48		3·41		1·04		7·22		2·20		9·75		2·97		10·595		3·35	
Best month	....	....	....	....	124·74	....	38·02	....	153·71	162·41	46·85	49·55	202·60	168·48	61·75	51·35	242·96	299·56	74·05	91·30
Average monthly progress	....	....	....	....	106·5	....	32·5	....	116·1	102·5	35·4	31·3	169·0	127·4	51·77	38·84	207·0	125·3	63·36	38·2

Months.	1866.		1866.		1867.		1867.		1868.		1868.		1869.		1869.		1870.		1870.	
	Bardonnèche.	Modane.	Bardonnèche.	Modane.	Bardonnèche.	Modane.	Bardonnèche.	Modane.	Bardonnèche.	Modane.	Bardonnèche.	Modane.	Bardonnèche.	Modane.	Bardonnèche.	Modane.	Bardonnèche.	Modane.	Bardonnèche.	Modane.
	Feet.		Metres.		Feet.		Metres.		Feet.		Metres.		Feet.		Metres.		Feet.		Metres.	
January	208·3	72·2	63·50	22·00	252·6	69·7	77·00	21·26	178·2	170·2	54·30	51·90	167·0	185·3	50·90	56·45	213·2	146·2	65·00	44·55
February	204·1	50·7	62·20	15·45	216·5	49·9	66·00	15·21	160·8	154·4	49·00	47·05	198·8	168·8	60·60	51·75	200·6	104·2	61·20	31·75
March	224·7	61·2	68·50	18·65	258·5	188·3	78·80	57·54	161·8	190·4	49·30	60·85	268·7	177·4	81·90	51·05	235·5	136·2	71·80	41·50
April	194·9	37·2	59·40	11·35	264·8	253·7	80·70	75·51	158·9	204·4	46·90	62·45	251·8	158·4	76·75	48·25	230·7	172·1	70·30	52·45
May	224·2	47·4	68·35	14·45	297·2	284·9	90·60	86·84	201·1	178·8	61·30	54·50	235·1	176·2	71·90	53·70	251·6	248·8	76·70	75·85
June	218·4	66·6	65·05	20·30	208·3	201·9	63·50	61·62	196·2	177·7	59·80	54·15	231·5	148·4	70·55	45·30	222·6	229·7	67·85	70·00
July	242·8	65·8	74·00	20·05	269·7	238·0	82·20	72·55	209·7	212·6	63·90	64·80	226·7	167·0	69·10	50·90	248·5	247·2	75·75	75·30
August	244·9	56·5	74·65	17·23	230·8	227·4	70·35	69·30	170·9	186·3	52·10	56·80	224·4	191·2	68·40	58·25	261·8	220·0	79·80	67·05
September	223·9	52·0	68·23	15·86	195·4	227·0	59·55	69·18	164·1	186·5	50·00	56·85	238·1	190·9	72·80	58·15	275·3	256·6	83·90	78·20
October	247·1	42·3	75·30	12·89	232·9	198·7	71·20	60·65	171·3	207·5	52·20	63·25	250·6	155·9	76·40	47·50	292·7	260·8	89·20	79·50
November	228·7	75·5	69·70	22·98	160·8	196·8	49·00	40·10	184·1	202·9	56·10	61·85	216·6	137·6	66·10	41·95	262·5	248·1	80·10	74·10
December	209·3	69·0	63·80	21·08	116·1	124·8	35·40	38·05	143·4	154·6	43·70	47·10	204·4	122·7	62·80	37·50	222·6†	182·4	67·85†	55·00
Total { One end	2664·3	696·5	812·70	212·20	2703·6	2261·6	824·30	687·81	2095·5	2235·3	638·60	681·55	2713·7	1979·8	827·70	603·75	2917·7	2447·3	889·45	745·85
Total { Both ends	3360·8		1024·99		4965·2		1512·11		4330·8		1320·15		4693·5		1481·45		5365·0		1635·30	
Daily Progress { One end	7·32	1·90	2·23	0·58	7·41	6·17	2·26	1·88	5·74	6·10	1·75	1·86	7·44	5·41	2·27	1·65	8·10	6·79	2·47	2·07
Daily Progress { Both ends	9·22		2·81		13·58		4·14		11·84		3·61		12·85		3·92		14·89		4·54	
Best month	247·1	75·5	75·3	23·00	297·2	284·9	90·6	86·84	209·7	212·6	63·90	64·8	268·7	191·2	81·9	58·25	292·7	260·8	89·2	79·5
Average monthly progress	222·2	58·0	67·7	17·69	225·3	188·5	68·7	57·32	174·6	186·3	53·22	56·8	226·1	165·0	68·98	50·31	243·2	203·9	74·12	62·15

* The first blast on the Modane side was fired August 18th, 1857; the first blast on the Bardonnèche side was fired November 14th, 1857. Machine-drilling was started on the Bardonnèche side January 12th, 1861; machine-drilling was started on the Modane side January 28th, 1862. The heading was at first driven about 10 feet square; later 9½ feet wide by 8½ feet high was settled on=80¾ square feet or 7·5 square metres.

† Headings met, December 25.

TABLE 49.

St. Gothard Tunnel.—*Progress of Heading.**

Months.	1872. Göschenen.	1872. Airolo.	1872. Göschenen.	1872. Airolo.	1873. Göschenen.	1873. Airolo.	1873. Göschenen.	1873. Airolo.	1874. Göschenen.	1874. Airolo.	1874. Göschenen.	1874. Airolo.	1875. Göschenen.	1875. Airolo.	1875. Göschenen.	1875. Airolo.	1876. Göschenen.	1876. Airolo.	1876. Göschenen.	1876. Airolo.
	Feet.		Metres.		Feet.		Metres.		Feet.		Metres.		Feet.		Metres.		Feet.		Metres.	
January	....	....	....	....	69.2†	78.1†	21.1†	23.8†	236.3	169.6	72.0	51.7	303.8	332.7	92.6	101.4	106.6	398.0	32.5	121.3
February	....	....	....	...	67.3†	59.4†	20.5†	18.1†	215.9	181.5	65.8	55.3	272.8	331.4	83.1	101.0	152.8	292.0	46.6	89.0
March	....	....	....	....	87.6†	70.5†	26.7†	21.5†	269.4	207.5	82.1	63.2	302.2	284.4	92.1	86.7	247.7	249.7	75.5	76.1
April	...	....	....	....	99.7	89.4	30.4	12.0	191.6	170.4	58.4	51.9	320.2	420.0	97.6	128.0	373.4	208.8	113.8	63.6
May	....	....	....	....	139.4	73.8†	42.5	22.5†	269.1	147.0	82.0	44.8	379.0	331.4	115.5	101.0	361.2	192.3	110.1	58.6
June	....	....	....	....	157.7	64.3†	48.1	19.6†	230.7	207.2	70.3	63.1	325.8	377.3	99.3	115.0	314.0	182.6	95.7	40.4
July	....	....	....	....	167.3	155.4	51.0	47.4	311.7	203.5	95.0	62.0	372.0	417.4	113.4	127.2	347.7	170.6	106.0	52.0
August	....	....	....	....	218.5	292.5	66.6	89.1	393.7	196.2	120.0	59.8	393.4	314.3	119.9	95.8	436.4	272.3	133.0	83.0
September	....	94.2†	....	28.7†	164.7	197.5	50.2	60.2	355.0	168.0	108.2	51.2	413.1	388.7	125.9	103.2	229.7	331.4	70.0	101.0
October	....	129.3†	....	39.4†	229.7	196.9	70.0	60.0	371.1	240.9	113.1	73.4	418.7	381.3	127.6	116.2	273.4	383.9	83.8	117.0
November	15.7†	57.7†	4.8†	17.6†	246.1	167.6	75.0	51.1	274.7	277.7	83.7	84.6	220.5	298.6	67.2	90.1	220.5	344.5	67.2	105.0
December	46.3†	52.5†	14.1†	16.0†	259.9	226.4	79.2	69.0	283.8	283.5	86.5	86.4	129.0	295.8	89.3	90.0	263.3	372.7	72.0	113.6
Total: One end	62.0	333.7	18.9	101.7	1907.1	1021.8	581.3	494.3	3403.0	2453.0	1087.1	747.4	3850.5	4119.8	1173.5	1255.6	3299.7	3348.8	1005.7	1020.6
Total: Both ends	395.7		120.6		3528.9		1073.6		5856.0		1784.5		7970.3		2429.1		6648.5		2026.3	
Best month	46.3	129.3	14.1	30.4	259.9	315.0	79.2	96.0	393.7	283.5	120.0	86.4	418.7	420.0	127.6	128.0	436.4	398.0	133.0	121.3
Average monthly progress	31.0	83.4	9.45	25.4	158.92	135.1	48.5	41.2	283.6	204.4	86.4	62.3	320.9	343.3	97.8	104.7	275.0	279.1	83.8	85.0

Months.	1877. Göschenen.	1877. Airolo.	1877. Göschenen.	1877. Airolo.	1878. Göschenen.	1878. Airolo.	1878. Göschenen.	1878. Airolo.	1879. Göschenen.	1879. Airolo.	1879. Göschenen.	1879. Airolo.	1880. Göschenen.	1880. Airolo.	1880. Göschenen.	1880. Airolo.
	Feet.		Metres.		Feet.		Metres.		Feet.		Metres.		Feet.		Metres.	
January	288.7	319.6	88.0	97.4	246.1	175.8	75.0	53.6	360.9	266.7	110.0	81.3	321.5	258.5	98.0	78.8
February	221.5	261.8	67.5	79.8	262.5	116.8	80.0	35.6	360.9	169.6	110.0	51.7	373.0‡	285.1‡	113.7‡	86.9‡
March	420.0	246.4	128.0	75.1	272.3	124.3	83.0	37.9	393.7	221.8	120.0	167.6	....	....	....	....
April	328.1	377.6	100.0	115.1	400.3	280.2	123.0	85.4	377.3	445.5	115.0	135.8	....	....	....	....
May	374.0	341.9	114.0	104.2	380.6	470.8	116.0	143.5	423.2	337.9	129.0	109.6	....	....	....	....
June	423.2	292.3	129.0	89.1	406.8	344.5	124.0	105.0	315.0	323.2	96.0	98.5	....	....	....	....
July	426.5	214.2	130.0	65.3	436.4	418.6	133.0	127.6	324.8	357.6	99.0	103.0	....	....	....	....
August	311.7	349.1	95.0	106.4	351.1	563.3	107.0	171.7	370.3	311.3	115.0	94.9	....	....	....	....
September	423.2	257.9	129.0	78.6	252.6	405.2	77.0	123.5	278.9	306.1	85.0	93.3	....	....	....	....
October	337.9	348.7	103.0	106.3	479.0	409.4	146.0	124.8	420.0	322.8	128.0	98.4	....	....	....	....
November	246.1	119.4	75.0	36.4	387.1	324.8	118.0	99.0	134.4	337.3	41.0	102.8	....	....	....	....
December	236.2	132.2	72.0	40.3	420.0	401.2	128.0	122.3	91.9	398.9	28.0	121.6	....	....	....	....
Total: One end	4037.1	3261.1	1230.5	994.0	4294.3	4084.9	1309.0	1229.9	3860.3	3800.7	1176.0	1158.5	694.5	543.6	211.7	165.7
Total: Both ends	7298.2		2224.5		8329.7		2538.9		7661.0		2334.5		1238.1		377.4	
Best month	426.5	377.6	130.0	115.1	479.0	563.3	146.0	171.7	423.2	445.5	129.0	135.8	373.0	285.1	113.7	86.9
Average monthly progress	334.8	271.8	102.5	82.8	357.9	336.2	109.1	102.4	321.7	316.7	98.0	96.5	347.2	271.8	105.8	82.8

* Area of the St. Gothard heading has been generally a little over 6 square metres: say 6.25 square metres, or 2.5 m. high, by 2.5 m. wide (8′ 2½″ square metres, or 67¼ square feet).

† Hand-drilling.

‡ Pierced February 29, 1880.

TABLE 50.

St. Gothard Tunnel—Record of Work during the Year 1880.

Goeschenen End.

	Top Heading.		Top Heading Enlargement.		Bottom Heading.*		Bottom Enlargement.		Arch Masonry.		East Abutment.		West Abutment.		Excavating and Arching Drain.	
	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.
Condition of work December 31st, 1879	24715.0	7533.0	22407.1	6857.0	17485.9	5329.6	15901.2	4846.6	17992.4	5484.0	13369.7	4075.0	15617.1	4742.0	12096.7	3687.0
Progress in January, 1880	321.5	98.0	304.8	92.9	160.1	48.8	442.9	134.9	190.3	58.0	442.9	135.0	203.4	62.0	....	....
" " February	373.0†	113.7†	234.9	71.6	199.5	60.8	329.4	100.4	190.3	58.0	334.6	102.0	150.9	46.0	....	....
" " March	....	....	400.3	122.0	201.8	61.5	139.1	42.4	331.4	101.0	311.7	95.0	98.4	30.0	846.5	258.0
" " April	....	....	590.9	180.1	289.7	88.3	86.9	26.5	485.6	148.0	269.0	82.0	....	....	446.2	136.0
" " May	....	....	392.1	119.5	260.8	79.5	230.6	70.3	456.0	139.0	210.0	64.0	....	....	....	....
" " June	....	....	372.4	113.5	406.5	123.9	323.2	98.5	390.4	119.0	190.3	58.0	....	....	1076.1	328.0
" " July	....	...	281.8	85.9	357.4	109.1	257.5	78.4	662.7	202.0	321.5	98.0	....	....	626.6	191.0
" " August	....	....	179.5	54.7	635.5	193.7	114.8	35.0	567.6	173.0	....	....	210.0	64.0	52.5	16.0
" " September	....	....	24.6	7.5	614.5	187.3	182.4	55.6	580.7	177.0	....	....	49.2	15.0	....	....
" " October	....	....	....	....	709.3	216.2	352.7	107.5	626.6	191.0	....	....	121.4	37.0	....	....
" " November	....	....	....	....	14954.9	455.8	1225.4	373.5	416.7	127.0	....	....	292.0	89.0	....	....
" " December	....	....	....	....												
Condition of work December 31st, 1880	25409.5	7744.7	25278.4	7704.7	22816.9	6954.5	20586.1	5067.6	22800.7	6977.0	15449.7	4709.0	16742.4	5085.0	15144.6	4616.0
Total Progress in 1872	62.8	18.9	....	....	....	....	....	....	....	....	....	....	....	....	....	....
" " " 1873	1907.1	581.3	870.8	265.4	332.1	101.2	23.0	7.0	....	....	....	....	....	....	....	....
" " " 1874	3403.0	1037.1	1296.7	395.2	1633.3	498.5	441.2	134.5	288.7	88.0	337.9	103.0	288.7	88.0	....	....
" " " 1875	3850.5	1173.5	2691.9	820.2	2556.6	779.2	1812.1	552.3	2115.5	644.8	1200.9	366.0	1217.3	371.0	....	....
" " " 1876	3299.7	1005.7	3824.7	1165.4	2536.6	773.1	3188.2	971.7	2087.3	636.2	3359.7	1024.0	2658.9	810.4	1738.9	530.0
" " " 1877	4037.1	1230.5	5559.1	1694.4	2825.8	861.3	2315.6	705.8	4581.4	1396.4	2860.9	872.0	2226.7	678.7	6573.6	2003.6
" " " 1878	4294.7	1309.0	4441.7	1353.8	3946.6	1202.9	4377.4	1334.2	6381.3	1945.0	3392.1	1339.0	3543.0	1079.9	2881.9	878.4
" " " 1879	3861.6	1177.0	3814.4	1162.6	3652.9	1113.4	3743.8	1141.1	2537.4	773.4	1217.2	371.0	5623.5	1714.0	738.2	225.0
" " " 1880	694.5	211.7	2781.3	847.7	5331.0	1624.9	3681.9	1121.0	4898.3	1493.0	2080.0	634.0	1125.3	343.0	3047.9	929.0

Airolo End.

	Top Heading.		Top Heading Enlargement.		Bottom Heading.*		Bottom Enlargement.		Arch Masonry.		East Abutment.		West Abutment.		Excavating and Arching Drain.	
	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.
Condition of the work December 31st, 1879	22972.9	7002.0	20056.8	6113.2	17485.6	5329.5	15359.5	4681.5	17156.8	5229.3	16187.7	4933.5	14127.5	4306.0	14058.6	4285.0
Progress in January, 1880	258.5	78.8	265.7	81.0	165.0	50.3	266.1	81.1	259.5	79.1	186.7	56.9	....	....	....	....
" " February	285.1†	86.9†	292.0	89.0	188.3	57.4	278.9	85.0	278.9	85.0	215.5	65.7	232.6	73.0	....	....
" " March	....	....	642.7	195.9	176.2	53.7	218.2	66.5	368.1	112.2	18.7	5.7	275.6	84.0	....	....
" " April	....	....	585.0	178.3	181.1	55.2	316.3	96.4	327.8	99.9	38.4	11.7	382.2	116.5	308.4	94.0
" " May	....	....	434.4	132.4	214.9	65.5	278.9	85.0	336.6	102.6	12.8	3.9	423.2	129.0	164.0	50.0
" " June	....	....	497.7	151.7	211.6	64.5	194.2	59.2	300.5	91.6	331.4	101.0	84.3	25.7	439.6	134.0
" " July	....	....	414.0	126.2	161.7	49.3	372.0	113.4	386.5	117.8	12.5	3.8	238.2	72.6	397.0	121.0
" " August	....	....	559.7	89.6	236.2	72.0	344.2	104.9	713.6	217.5	....	....	74.8	22.8	....	....
" " September	....	....	34.1	10.4	471.8	143.8	258.3	78.8	864.8	263.6	....	....	136.5	41.6	....	....
" " October	....	....	....	....	601.1	183.2	324.1	98.8	908.1	276.8	....	....	289.7	88.3	449.5	137.0
" " November	....	....	....	....	1196.9	364.8	1001.3	305.2	1080.1	329.2	....	....	694.6	211.7		
" " December	....	....	....	....												
Condition of work December 31st, 1880	23516.5	7167.7	23782.1	7247.7	21290.4	6589.2	19212.0	5855.8	22961.3	7004.6	17008.7	5182.2	16959.2	5171.2	15817.1	4821.0
Total progress in 1872	333.7	101.7	127.9	39.0	....	....	....	....	42.6	13.0	....	....	....	....	....	....
" " " 1873	1621.8	494.3	725.1	221.0	511.8	156.0	511.8	156.0	433.1	132.0	334.3	101.9	465.0	141.6	378.9	115.3
" " " 1874	2453.0	747.4	1299.0	396.0	183.8	56.0	259.2	79.0	485.5	184.8	....	....	....	....	36.5	10.7
" " " 1875	4119.8	1255.6	1628.0	496.0	2063.7	629.0	967.9	295.0	1641.0	500.2	0.3	0.1	1930.5	588.4	....	....
" " " 1876	3348.5	1020.6	4294.8	1309.0	2739.6	835.0	1935.8	590.0	2364.0	720.0	2087.0	636.2	1294.0	394.3	19.7	6.0
" " " 1877	3261.2	994.0	5380.7	1640.0	4045.3	1233.0	4019.1	1225.0	5412.5	1649.7	3979.7	1213.0	4988.9	1520.5	8087.0	2465.0
" " " 1878	4035.2	1229.9	3208.7	978.0	4740.9	1445.0	3956.7	1206.0	4434.3	1351.6	3779.8	1152.0	4092.3	1247.3	3946.9	1203.0
" " " 1879	3800.9	1158.5	3396.4	1035.2	3200.5	975.5	3709.1	1130.5	2224.4	678.0	3642.8	1830.3	1358.0	413.9	1591.2	485.0
" " " 1880	543.6	165.7	3725.3	1134.5	3.04.8	1159.7	3852.5	1174.3	5824.5	1775.3	816.0	248.7	2831.7	863.2	1758.5	536.0

* This is the "Cunette du Strosse," or advance cut of the bottom: not a true heading, as the top is already out.

† Pierced February 29, 1880.

TABLE 51.

St. Gothard Tunnel—Goeschenen End.

*Machine-Drilling Record.**

1873.

		Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Rock-Drill Used.	Dubois and François—McKean and Sommeiller.												
1. Number of boring attacks.	....	....	....	....	37	51	52	56	70	58	77	73	85
2. Average time for drill-work proper, in one attack†	....	....	....	....	8-42	8-40	8-16	6-43	5-41	7-00	5-08	4-30	4-40
3. Average time for blasting and clearing in one attack†	....	....	....	....	8-38	5-54	5-41	5-08	5-02	5-13	4-13	4-46	3-59
4. Total time for one boring attack†.	....	....	....	....	17-20	14-32	13-57	11-51	10-43	12-22	9-21	9-16	8-30
5. Number of holes drilled during month	....	....	....	....	1096	1389	1387	1477	1881	1535	1819	1800	2040
6. Average number of holes drilled per attack	....	....	....	....	29·62	27·24	26·67	26·37	26·87	26·47	23·62	24·00	24·00
7. Total ength of all holes drilled during month	Feet. Metres.	....	....	... .	3747·0 1142·0	4410·0 1344·0	4695·0 1431·0	4761·0 1451·4	619·10 1886·5	5036·0 1535·0	5975·0 1820·8	6569·0 2002·4	6834·0 2083·2
8. Average total length of holes in one attack‡	Feet. Metres.	....	....	....	101·2 30·87	86·1 26·35	90·3 27·52	85·0 25·91	88·1 26·95	86·4 26·47	78·6 23·95	87·6 26·70	80·4 24·51
9. Average length of single holes drilled during month§	Feet. Metres.	....	....	....	3·42 1·042	3·18 0·968	3·39 1·032	3·21 0·983	3·29 1·003	3·28 1·000	3·28 1·001	3·65 1·112	3·25 1·021
10. Sum of average single lengths of bore-holes for all attacks in the month‖	Feet. Metres.	....	....	....	126·8 28·65	161·9 49·37	176·0 53·66	180·6 55·05	230·4 70·21	190·3 58·00	252·9 77·08	273·7 83·40	284·7 86·78
11. Number of machines sent to repair-shops	....	....	....	....	36	91	64	64	125	145	158	163	224
12. Average lineal advance of heading per attack¶	Feet. Metres.	....	....	....	2·5 ·82	2·71 ·83	3·01 ·92	2·98 ·91	3·11 ·95	2·81 ·86	2·98 ·91	3·28 1·00	3·02 ·92

1874.

		Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Rock-Drill Used.		Same and Ferroux	Dubois and François.			Same and Ferroux.	Ferroux.						
1. Number of boring attacks	....	76	74	85	67	69 F. 22 D-F.	78	91	100	102	115	84	90
2. Average time for drill-work proper in one attack†	....	4-48	5-08	5-04	6-05	4-51 F. 4-39 F.	5-27	4-53	3-27	3-41	3-21	4-27	5-07
3. Average time for blasting and clearing in one attack†	....	3-42	3-58	3-37	3-29	3-21 F. 3-21 D-F.	3-25	3-18	3-20	3-17	3-08	3-07	3-08
4. Total time† for one boring attack.	....	8-32	9-06	8-41	9-34	8-12 F. 8-00 D-F.	8-52	8-11	6-47	6-58	6-29	7-34	8-15
5. Number of holes drilled during month	....	1824	1775	2023	1607	1654 F. 528 D-F.	1968	2203	2211	1937	2302	1684	1938
6. Average number of holes drilled per attack	....	24·00	23·99	23·80	23·98	23·97 F. 24·00 D-F.	25·23	24·21	20·28	19·34	20·02	20·05	21·53
7. Total length of all holes drilled during month	Feet. Metres.	6031·0 1838·0	5998·0 1828·0	6972·0 2125·0	5367·0 1636·0	5441·0 F. 1659·0 F. 1782·0 D-F. 528·0 D-F.	6517·0 1986·0	8324·0 2537·0	8806·0 2684·0	7615·0 2321·0	8114·0 2473·0	1955·0 1815·0	6772·0 2064·0
8. Average total length of holes in one attack‡	Feet. Metres.	79·4 24·19	80·8 24·66	82·00 24·99	80·0 24·41	78·7 F. 24·04 F. 78·7 D-F. 24·00 D-F.	83·5 25·45	90·9 27·88	80·7 24·62	74·5 22·75	70·5 21·50	70·8 21·61	75·1 22·93
9. Average length of single holes drilled during month§	Feet. Metres.	3·31 1·008	3·37 1·028	3·45 1·050	3·33 1·018	3·29 F. 1·003 F. 3·28 D-F. 1·000 D-F.	3·31 1·009	3·77 1·152	3·98 1·214	3·76 1·167	3·53 1·074	3·54 1·078	3·49 1·065
10. Sum of average single lengths of bore-holes for all attacks in the month‖	Feet. Metres.	249·5 76·01	249·6 76·07	292·6 89·25	223·7 68·20	227·1 F. 69·20 F. 72·1 D-F. 22·00 D-F.	257·8 78·60	345·0 104·9	438·3 133·6	394·0 120·1	406·1 123·7	293·4 89·50	314·0 95·70
11. Number of machines sent to repair-shops.	....	168	198	182	113	64 F. 36 D-F.	94	114	74	78	79	75	76
12. Average lineal advance of heading per attack¶	Feet. Metres.	2·91 ·88	2·94 ·89	3·08 ·96	2·88 ·87	·84 D-F. 2·74 D-F. 3·01 F. ·92 F.	2·91 ·88	3·29 1·04	3·31 1·1	3·30 1·00	3·28 1·00	3·22 ·98	2·78 ·85

* These figures are from the "Geschäftsberichten der Direktion und des Verwaltungsrathes der Gotthardtbahn," for 1873, 1874, 1875, and 1876. (Also see revised tables in Ržiha's "Eisenbahn- Unter- und Oberbau," Vienna, 1876.)

† In hours and minutes.

‡ These figures are obtained by dividing the metres in line 7 by figures in line 1.

§ Obtained by dividing metres in line 7 by figures in line 5

‖ Obtained by multiplying metres in line 9 by figures in line 1.

¶ Obtained by dividing the monthly advance (in Table 49) by the figures in line 1 of this Table. By comparing this line (12) with the average lengths of single holes (line 9), it will be seen that the average advance per attack is, in general, nearly equal to the average length of hole.

TABLE 51. (*Continued*).

1875.

		Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Rock-Drill Used.	Ferroux.												
1. Number of boring attacks...	....	94	83	90	93	109	94	103	105	109	106	67	25
2. Average time for drill-work proper in one attack*.	....	4-32	4-47	5-00	4-35	3-15	4-25	3-43	3-39	3-21	3-12	4-20	2-54
3. Average time for blasting and clearing in one attack*.........	....	3-17	3-18	3-16	3-08	3-03	3-16	3-10	3-02	3-08	3-16	4-21	6-17
4. Total time for one boring attack.*	....	7-49	8-05	8-16	7-43	6-21	7-41	6-55	6-41	6-29	6-28	8-41	9-11
5. Number of holes drilled during month	....	1987	1678	1811	1850	1992	1773	1844	1773	1952	1651	827	263
6. Average number of holes drilled per attack.....................	....	21·14	20·22	20·12	19·89	18·28	18·86	17·90	16·89	16·07	15·57	12·34	10·60
7. Total length of all holes drilled during month.........	Feet. Metres.	6946·0 2117·0	5893·0 1796·0	6827·0 2081·0	6998·0 2133·0	7648·0 2331·0	6660·0 2030·0	7192·0 2192·0	6917·0 2108·0	6897·0 2102·0	6550·0 1996·0	2750·0 838·0	873·0 266·0
8. Average total length of holes in one attack†..	Feet. Metres.	73·7 22·52	70·8 21·64	75·7 23·12	75·1 22·94	70·1 21·30	70·8 21·60	69·8 21·28	65·9 20·08	63·3 19·28	61·8 18·8	41·04 12·5	34·9 10·6
9. Average length of single holes drilled during month‡....	Feet. Metres.	3·49 1·065	3·51 1·070	3·76 1·149	3·77 1·153	3·84 1·170	3·75 1·145	3·91 1·189	3·91 1·189	3·94 1·200	3·97 1·209	3·32 1·013	3·30 1·004
10. Sum of average single lengths of bore-holes for all attacks in the month§	Feet. Metres.	336·2 102·5	282·6 86·17	336·5 102·6	351·6 107·2	418·5 127·6	353·2 107·7	401·5 122·4	409·4 124·8	429·2 130·8	420·3 128·20	222·8 67·90	82·3 25·10
11 Number of machines sent to repair-shops.....................	....	81	77	84	72	42	58	38	29	15	13	16	1
12. Average lineal advance of heading per attack‖.....................	Feet. Metres.	3·28 0·993	3·22 0·98	3·29 1·03	3·29 1·05	3·30 1·06	3·30 1·06	3·31 1·1	3·32 1·14	3·32 1·15	3·94 1·20	3·28 1·003	5·15 1·57

1876.

		Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Rock-Drill Used.	3-4. Ferroux.						4. Ferroux.						
1. Number of boring attacks.... ...	....	5	35	78	104	106	90	109	123	70	93	75	72
2. Average time for drill-work proper in one attack*.............	....	3-30	3-20	3-36	3-00	3-46	3-17	3-27	2-54	4-19	3-34	3-18	5-19
3. Average time for blasting and clearing in one attack*.........	....	4-18	3-50	3-57	3-43	3-13	2-50	2-57	2-56	2-54	2-57	3-16	4-12
4. Total time for one boring attack.*	....	7-48	7-19	7-33	6-43	6-59	6-07	6-24	5-50	7-23	6-31	6-34	9-31
5. Number of holes drilled during month	....	54	344	863	1318	1437	1200	1756	1920	1204	1405	867	1007
6. Average number of holes drilled per attack.....................	....	11	10	11	13	14	13	16	16	16	15	12	14
7. Total length of all holes drilled during month.........	Feet. Metres.	177·0 54·0	1181·0 360·0	2871·0 875·0	4698·0 1432·0	5236·0 1596·0	4452·0 1357·0	6365·0 1940·0	7395·0 2254·0	4629·0 1411·0	5463·0 1665·0	3383·0 1031·0	3904·0 1190·0
8. Average total length of holes in one attack†.....................	Feet. Metres.	35·43 10·8	33·66 10·26	36·81 11·22	45·18 13·77	49·41 15·06	49·48 15·08	58·40 17·80	60·11 18·32	60·93 18·57	58·73 17·90	45·11 13·75	54·23 16·53
9. Average length of single holes drilled during month‡	Feet. Metres.	3·28 1·00	3·38 1·03	3·21 1·01	3·68 1·09	3·64 1·11	3·71 1·13	3·61 1·10	3·90 1·19	3·84 1·17	3·90 1·19	3·90 1·19	3·87 1·18
10. Sum of average single lengths of bore-holes for all attacks in the month§	Feet. Metres.	16·4 5·0	119·1 36·3	259·2 79·0	370·4 112·9	386·2 117·7	367·8 112·1	394·4 120·2	474·8 144·7	292·7 89·2	361·9 110·3	291·7 88·9	289·9 85·3
11. Number of machines sent to repair-shops.....................	....	....	3	11	18	14	11	12	17	15	15	8	13
12. Average lineal advance of heading per attack‖.....................	Feet. Metres.	....	....	3·18 0·97	3·58 1·09	3·41 1·04	3·48 1·06	3·18 0·97	3·54 1·08	3·03 0·92	2·95 0·90	2·95 0·90	3·28 1·0

* In hours and minutes.
† These figures are obtained by dividing the metres in line 7 by figures in line 1.
‡ Obtained by dividing metres in line 7 by figures in line 5.
§ Obtained by multiplying metres in line 9 by figures in line 1.
‖ Obtained by dividing the monthly advance (in Table 49) by the figures in line 1 of this Table. By comparing this line (12) with the average lengths of single holes (line 9), it will be seen that the average advance per attack is, in general, nearly equal to the average length of hole.

TABLE 51. (*Continued*).

1877.

		Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Rock-Drill Used.	Ferroux.												
1. Number of boring attacks........	....	77	59	103	81	90	104	106	88	106	87	69	65
2. Average time for drill-work proper in one attack*.............	....	5-26	4-56	2-55	3-4	3-13	2-38	*2-43	2-53	3-10	3-48	6-27	6-51
3. Average time for blasting and clearing in one attack*.........	....	4-8	4-29	4-15	5-10	4-40	4-7	4-17	4-32	3-29	4-15	3-52	3-53
4. Total time for one boring attack*.	....	9-34	9-25	7-10	8-14	8-2	6-45	7-	7-25	6-39	8-3	10-19	10-44
5. Number of holes drilled during month..........................	....	1291	1088	1749	1305	1543	1771	1838	1441	1919	1641	1528	1467
6. Average number of holes drilled per attack......................	....	16.77	18.44	16.98	16.11	17.14	17.03	17.34	17.36	18.10	18.86	22.14	22.57
7. Total length of all holes drilled during month.................	Feet. Metres.	5339.0 1597.1	4224.2 1318.1	7225.5 2202.3	5277.2 1608.7	6666.7 2032.0	7735.4 2367.8	7999.5 2438.2	5603.9 1708.3	7596.4 2315.5	6516.2 1986.1	6078.5 1852.8	5701.5 1737.8
8. Average total length of holes in one attack†....................	Feet. Metres.	68.0 20.7	73.3 22.3	70.1 21.4	65.1 19.8	74.1 22.6	74.4 22.8	75.5 23.0	63.7 19.4	71.7 21.9	74.7 22.8	88.1 26.8	87.7 26.7
9. Average length of single holes drilled during month‡..........	Feet. Metres.	4.91 1.24	3.97 1.21	4.13 1.26	4.03 1.23	4.33 1.32	4.35 1.33	4.33 1.32	3.87 1.18	3.97 1.21	4.35 1.33	3.97 1.21	3.94 1.20
10. Sum of average single lengths of boreholes for all attacks in the month §........................	Feet. Metres.	378.07 95.48	235.03 71.39	425.39 129.78	326.43 99.63	389.70 118.80	452.40 138.32	458.98 139.92	340.56 103.84	420.82 128.26	380.45 115.71	273.98 83.49	256.10 78.00
11. Number of machines sent to repair-shops.....................	....	17	10	4	8	6	13	26	21	23	28	66	54
12. Average lineal advance of heading per attack‖.....................	Feet. Metres.	3.74 1.14	3.74 1.14	4.07 1.24	4.03 1.23	4.16 1.27	4.07 1.24	4.03 1.23	3.74 1.14	4.00 1.22	3.87 1.18	3.57 1.09	3.64 1.11

1878.

		Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Rock-Drill Used.	Ferroux.												
1. Number of boring attacks........	....	69	71	75	97	84	91	98	82	63	111	92	100
2. Average time for drill-work proper in one attack*.............	....	7-11	5-51	6-4	3-38	4-4	3-51	3-44	4-35	7-14	2-58	4-14	3-11
3. Average time for blasting and clearing in one attack*.........	....	3-36	3-33	3-46	3-36	3-42	3-46	3-41	4-27	4-18	3-34	3-29	3-28
4. Total time for one boring attack*.	....	10-47	9-24	10-50	7-14	7-46	7-37	7-25	9-2	11-32	6-32	7-43	6-39
5. Number of holes drilled during month..........................	....	1353	1478	1631	1921	1732	1906	2078	1656	1304	2186	1873	2052
6. Average number of holes drilled per attack......................	....	22.51	20.82	21.75	19.80	20.62	20.94	21.20	20.19	20.70	19.69	20.36	20.52
7. Total length of all holes drilled during month.................	Feet. Metres.	5966.9 1818.7	5789.4 1764.6	6391.7 1948.2	8101.8 2469.4	7955.5 2424.8	8717.3 2657.0	9788.5 2983.5	7378.0 2248.8	5402.8 1646.6	9771.5 2978.3	8299.6 2529.7	9389.9 2862.0
8. Average total length of holes in one attack†....................	Feet. Metres.	86.48 26.36	81.52 24.85	85.23 25.98	83.53 25.46	83.80 28.87	83.01 28.21	99.87 30.44	89.96 27.42	85.73 26.13	88.02 26.83	90.19 27.49	93.90 28.62
9. Average length of single holes drilled during month‡..........	Feet. Metres.	3.84 1.17	3.90 1.19	3.90 1.19	4.23 1.29	4.59 1.40	4.56 1.39	4.69 1.43	4.46 1.36	4.13 1.26	4.46 1.36	4.43 1.35	4.56 1.39
10. Sum of average single lengths of bore-holes for all attacks in the month§........................	Feet. Metres.	264.96 80.73	276.90 84.49	292.50 89.25	410.31 125.13	385.56 117.60	414.96 126.49	459.62 140.14	365.72 111.52	260.19 79.38	495.06 150.96	407.56 124.20	456.00 139.00
11. Number of machines sent to repair-shops.....................	....	62	41	35	25	23	24	18	30	27	30	36	23
12. Average lineal advance of heading per attack‖.....................	Feet. Metres.	3.58 1.09	3.71 1.13	3.64 1.11	4.13 1.26	4.53 1.38	4.46 1.36	4.46 1.36	4.26 1.30	4.00 1.22	4.30 1.31	4.20 1.28	4.20 1.28

* In hours and minutes.
† These figures are obtained by dividing the metres in line 7 by figures in line 1.
‡ Obtained by dividing metres in line 7 by figures in line 5.
§ Obtained by multiplying metres in line 9 by figures in line 1.
‖ Obtained by dividing the monthly advance (in Table 49) by the figures in line 1 of this Table. By comparing this line (12) with the average lengths of single holes (line 9), it will be seen that the average advance per attack is, in general, nearly equal to the average length of hole.

TABLE 51. (*Continued.*)

1879.

		Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
ROCK-DRILL USED.	Ferroux.												
1. Number of boring attacks........	....	96	95	108	95	106	84	94	107	76	108	36	22
2. Average time for drill-work proper in one attack*..............	....	4-30	3-48	3-52	4-11	3-24	5-10	4-28	3-23	2-52	2-35	1-33	1-56
3. Average time for blasting and clearing in one attack*.........	....	3-15	3-9	3-12	3-17	3-10	3-21	3-2	3-36	3-33	3-23	5-25	7-54
4. Total time for one boring attack*.	....	7-45	6-57	7-4	7-28	6-34	8-31	7-30	6-59	6-25	5-58	6-58	9-50
5. Number of holes drilled during month........................	....	2176	2258	2345	2127	2325	1907	2270	2418	1760	2543	400	188
6. Average number of holes drilled per attack.....................	....	22.67	23.77	22.77	22.39	21.93	22.70	24.15	22.60	23.16	22.71	11.11	8.54
7. Total length of all holes drilled during month.................	Feet. Metres.	9494.9 2891.8	9881.1 3011.7	9983.7 3043.0	9083.4 2768.6	9822.6 2993.9	7928.3 2416.5	8892.5 2710.4	10172.1 3100.4	7028.7 2142.3	10415.2 3174.5	1740.5 413.5	554.1 168.9
8. Average total length of holes in one attack†....................	Feet. Metres.	98.77 30.12	104.01 31.70	96.92 29.54	95.58 29.13	92.66 28.24	94.40 28.77	94.59 28.83	95.05 28.97	92.49 28.19	96.42 29.39	37.69 11.49	25.17 7.67
9. Average length of single holes drilled during month‡..........	Feet. Metres.	4.36 1.33	4.36 1.33	4.26 1.30	4.26 1.30	4.23 1.29	4.17 1.27	3.90 1.19	4.20 1.28	4.00 1.22	4.10 1.25	3.38 1.03	2.95 0.90
10. Sum of average single lengths of bore-holes for all attacks in the month§.......................	Feet. Metres.	418.56 127.68	414.20 126.35	438.78 133.90	414.70 123.50	448.35 136.74	350.28 106.68	366.60 111.86	449.40 136.96	304.00 92.72	442.80 135.00	121.68 37.08	64.90 19.80
11. Number of machines sent to repair-shops.....................	....	55	25	28	....	....	....	24	22	10	10	1	1
12. Average lineal advance of heading per attack‖....................	Feet. Metres.	3.77 1.15	3.81 1.16	3.81 1.16	3.97 1.21	4.00 1.22	3.74 1.14	3.44 1.05	3.51 1.07	3.67 1.12	3.87 1.18	3.08 0.94	2.53 0.77

1880.

		Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
ROCK-DRILL USED.	Ferroux.												
1. Number of boring attacks........	....	96	99			The two headings met on the 29th of February, 1880.							
2. Average time for drill-work proper in one attack*..............	....	3-49	3-17										
3. Average time for blasting and clearing in one attack*.........	....	3-54	3-18										
4. Total time for one boring attack*.	....	7-43	6-35										
5. Number of holes drilled during month........................	....	1989	2241										
6. Average number of holes drilled per attack.....................	....	20.72	22.64										
7. Total length of all holes drilled during month.................	Feet. Metres.	7660.9 2335.0	8786.8 2678.2										
8. Average total length of holes in one attack†....................	Feet. Metres.	79.78 24.32	88.79 27.06										
9. Average length of single holes drilled during month‡..........	Feet. Metres.	3.84 1.17	3.90 1.19										
10. Sum of average single lengths of bore-holes for all attacks in the month§.......................	Feet. Metres.	368.52 112.32	386.10 117.81										
11. Number of machines sent to repair shops.....................	....	19	12										
12. Average lineal advance of heading per attack‖....................	Feet. Metres.	3.35 1.02	3.77 1.15										

* In hours and minutes.
† These figures are obtained by dividing the metres in line 7 by figures in line 1.
‡ Obtained by dividing metres in line 7 by figures in line 5.
§ Obtained by multiplying metres in line 9 by figures in line 1.
‖ Obtained by dividing the monthly advance (in Table 49) by the figures in line 1 of this Table. By comparing this line (12) with the average lengths of single holes (line 9), it will be seen that the average advance per attack is, in general, nearly equal to the average length of hole.

TABLE 52.

St. Gothard Tunnel—Airolo End.

*Machine-Drilling Record.**

1873.

Rock-Drill Used.		Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	Dubois and François—Sommeiller and McKean.												
1. Number of boring attacks....	....	....	....	....	....	....	....	70	89	74	78	70	77
2. Average time for drill-work proper in one attack†	...	...	....	....	....	....	....	3-10	2-32	3-12	3-31	4-09	3-35
3. Average time for blasting and clearing in one attack†	....	....	....	....	....	....	...	7-29	5-31	6-37	5-58	5-42	6-07
4. Total time for one boring attack†.	....	....	....	....	....	....	....	10-39	8-03	9-49	9-29	9-51	9-42
5. Number of bore-holes drilled during month...	....	....	....	....	....	....	....	758	1100	1170	1293	1037	1272
6. Average number of holes drilled per attack	....	....	....	....	...	....	....	10·83	12·36	15·81	16·58	14·81	16·52
7. Total length of all holes drilled during month	Feet. Metres.	....	....	....	....	... .	....	2745·0 837·0	4354·0 1327·0	4524·0 1379·0	4652·0 1418·0	3681·0 1122·0	4954·0 1510·0
8. Average total length of holes in one attack‡	Feet. Metres.	....	....	....	....	....	....	39·24 11·96	49·0 14·91	61·1 18·64	59·6 18·18	52·6 16·02	64·4 19·62
9. Average length of single holes drilled during month§	Feet. Metres.	....	....	....	.... ..	....	....	3·62 1·105	3·96 1·207	3·89 1·179	3·60 1·097	3·54 1·082	3·91 1·187
10. Sum of average single lengths of bore-holes for all attacks in the month‖	Feet. Metres.	....	....	....	....	... .	....	252·8 77·35	352·3 107·42	285·9 87·25	280·7 85·57	248·3 75·74	300·2 91·40
11. Number of machines sent to repair-shops	....	....	....	....	....	....	....	14	17	20	25	25	55
12. Average lineal advance of heading per attack ¶	Feet. Metres.	....	....	....	....	....	....	2·29 0·69	3·28 1·001	2·65 0·81	2·52 0·77	2·22 0·73	2·94 0·896

1874.

Rock-Drill Used.		Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
		Dubois and François.					Dubois and François and McKean.			Same and Ferroux	Dubois and François and Ferroux.		Dubois and Fr'nçois
1. Number of boring attacks	....	61	54	65	59	55	66	63	64	55	81	85	83
2. Average time for drill-work proper in one attack†	....	5-25	3-12	4-0	6-29	8-06	6-01	7-10	7-52	8-21	5-14	4-46	4-12
3. Average time for blasting and clearing in one attack†	....	6-45	6-56	7-4	5-47	5-30	4-47	4-31	3-46	4-15	3-58	3-36	4-00
4. Total time for one boring attack†.	....	12-10	10-08	11-4	12-16	13-36	10-48	11-41	11-38	12-36	9-13	8-22	8-12
5. Number of bore-holes drilled during month	....	1273	817	1075	1178	1214	1468	1391	1777	1523	1570	1672	1580
6. Average number of holes drilled per attack	....	20·87	15·13	19·72	19·97	22·07	22·24	22·08	27·77	27·69	19·38	19·44	19·27
7. Total length of all holes drilled during month	Feet. Metres.	4754·0 1450·0	3150·0 960·0	4206·0 1282·0	4580·0 1396·0	4879·0 1487·0	5827·0 1776·0	5469·0 1667·0	6860·0 2091·0	5719·0 1743·0	5485·0 1672·0	6083·0 1854·0	5830·0 1777·0
8. Average total length of holes in one attack‡	Feet. Metres.	77·0 23·77	58·3 17·78	76·0 23·53	76·3 23·66	88·7 27·04	88·3 26·91	87·8 26·46	107·2 32·67	104·0 31·69	67·4 20·64	70·5 21·56	70·9 21·67
9. Average length of single holes drilled during month§	Feet. Metres.	3·74 1·139	3·77 1·175	3·92 1·193	3·90 1·185	4·01 1·225	3·96 1·210	3·94 1·198	3·89 1·177	3·76 1·145	3·50 1·065	3·63 1·100	3·60 1·125
10. Sum of average single lengths of bore-holes for all attacks in the month‖	Feet. Metres.	228·0 69·48	208·1 63·45	253·4 77·54	229·0 69·80	217·3 66·20	262·0 79·90	247·9 75·55	247·4 75·40	206·5 62·90	282·6 86·20	306·8 93·35	301·9 91·95
11. Number of machines sent to repair-shops	....	63	30	38	53	68	81	93	105	83	94	70	72
12. Average lineal advance of heading per attack ¶	Feet. Metres.	2·78 0·85	2·87 0·876	3·17 0·966	2·89 0·88	2·65 0·81	3·13 0·956	3·23 0·984	3·06 0·934	3·05 0·93	2·97 0·906	0·323 0·984	3·30 1·05

* These figures are from the "Geschäftsberichten der Direktion und des Verwaltungsrathes der Gotthardtbahn," for 1873, 1874, 1875, and 1876. (Also see revised tables in Rziha's "Eisenbahn- Unter- und Oberbau," Wien, 1876.)
† In hours and minutes.
‡ These figures are obtained by dividing the metres in line 7 by figures in line 1.
§ Obtained by dividing metres in line 7 by figures in line 5.
‖ Obtained by multiplying metres in line 9 by figures in line 1.
¶ Obtained by dividing the monthly advance (in Table 49) by the figures in line 1 of this Table. By comparing this line (12) with the average lengths of single holes (line 9), it will be seen that the average advance per attack is, in general, nearly equal to the average length of hole

TABLE 52. (*Continued.*)

1875.

Rock-Drill Used.		Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
		Dubois and François.		Same and partly McK'n.	Dubois and François and McKean.		Dubois and François.		Dubois and François and McKean.			McKean.	
1. Number of boring attacks........	....	98	93	83	114	95	110	118	92	99	107	80	89
2. Average time for drill-work proper in one attack*..............	....	3-29	3-46	6-06	3-35	3-42	3-43	3-31	4-53	3-54	3-15	2-36	3-18
3. Average time for blasting and clearing in one attack*.........	....	3-53	3-13	2-50	2-41	2-39	2-45	2-47	3-04	3-17	3-09	3-51	3-32
4. Total time for one boring attack*.	....	7-22	6-59	8-56	6-16	6-21	6-28	6-18	7-57	7-11	6-24	6-27	6-50
5. Number of bore-holes drilled during month......................	...	1775	1727	1529	1878	1563	1905	2045	1487	1635	1759	1090	1347
6. Average number of holes drilled per attack	....	18·11	18·57	18·42	16·33	16·28	17·32	17·33	16·16	16·52	16·44	13·62	15·13
7. Total length of all holes drilled during month..................	Feet. Metres.	6523·0 1988·0	6572·0 2003·0	5617·0 1712·0	7160·0 2182·0	5650·0 1722·0	6976·0 2126·0	7602·0 2317·0	5381·0 1635·0	5856·0 1785·0	6631·0 2021·0	4095·0 1248·0	4633·0 1412·0
8. Average total length of holes in one attack†..........	Feet. Metres.	66·6 20·29	70·4 21·54	67·7 20·63	61·3 18·97	58·8 17·94	63·4 19·33	64·5 19·63	58·3 17·78	59·1 18·08	60·06 18·32	51·2 15·61	52·1 15·85
9. Average length of single holes drilled during month‡...........	Feet. Metres.	3·64 1·120	3·78 1·160	3·64 1·120	3·79 1·162	3·62 1·102	3·64 1·116	3·66 1·133	3·63 1·100	3·59 1·092	3·78 1·149	3·76 1·145	3·41 1·048
10. Sum of average single lengths of bore-holes for all attacks in the month§.........................	Feet. Metres.	359·2 109·5	354·9 108·2	303·9 92·6	438·8 133·6	348·2 105·8	402·8 122·8	438·8 133·6	333·2 101·2	354·6 108·1	403·1 122·9	307·2 91·6	306·7 93·3
11. Number of machines sent to repair-shops........................	....	49	69	81	76	58	57	58	61	43	31	21	26
12. Average lineal advance of heading per attack‖.....................	Feet. Metres.	3·29 1·03	3·31 1·09	3·20 1·04	3·32 1·13	3·30 1·06	3·30 1·05	3·31 1·08	3·30 1·04	3·30 1·04	3·31 1·08	3·32 1·14	3·28 1·01

1876.

Rock-Drill Used.		Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
		5-6. McKean.					5. McKean.		4-5. McKean.		5. McKean.		
1. Number of boring attacks........	....	117	87	75	62	60	45	59	88	98	118	108	110
2. Average time for drill-work proper in one attack*..............	....	3-16	4-12	5-31	6-32	6-06	7-40	8-43	5-16	3-14	3-30	3-42	3-42
3. Average time for blasting and clearing in one attack*	....	2-59	3-36	4-28	4-05	4-37	4-36	3-50	3-33	3-24	2-58	3-02	3-06
4. Total time for one boring attack*.	....	6-25	7-48	9-59	10-37	10-43	12-16	12-33	8-49	6-38	6-28	6-42	6-48
5. Number of bore-holes drilled during month......................	....	1925	1402	1211	993	930	695	961	1383	1603	2058	1982	2070
6. Average number of holes drilled per attack......................	....	16	16	16	16	16	15	16	17	16	18	19	19
7. Total length of all holes drilled during month.......	Feet. Metres.	7021·0 2140·0	5046·0 1538·0	4292·0 1308·0	3504·0 1068·0	3379·0 1030·0	2497·0 761·0	3537·0 1078·0	5000·0 1524·0	5850·0 1783·0	7415·0 2260·0	7107·0 2166·0	7504·0 2287·0
8. Average total length of holes in one attack†................. ..	Feet. Metres.	43·2 13·16	58·0 17·69	57·2 17·44	56·5 17·23	56·3 17·16	55·5 16·91	59·9 18·27	61·0 18·60	59·7 18·19	65·6 20·0	69·0 21·03	68·2 20·79
9. Average length of single holes drilled during month‡..........	Feet. Metres.	3·64 1·11	3·6 1·10	3·54 1·08	3·58 1·09	3·51 1·07	3·6 1·10	3·64 1·11	3·6 1·10	3·64 1·11	3·6 1·10	3·58 1·09	3·64 1·11
10. Sum of average single lengths of bore-holes for all attacks in the month§	Feet. Metres.	427·2 130·2	313·2 95·45	265·9 81·05	221·6 67·55	211·3 64·4	161·8 49·3	215·6 65·7	299·4 91·25	358·3 109·2	407·3 124·15	369·7 112·7	399·4 121·6
11. Number of machines sent to repair-shops......................	....	25	22	34	29	28	33	84	58	41	31	53	38
12. Average lineal advance of heading per attack‖....................	Feet. Metres.	3·6 1·10	3·26 1·02	3·33 1·01	3·38 1·03	3·21 0·98	2·95 0·90	2·89 0·88	3·28 1·0	3·38 1·03	3·38 1·03	3·26 1·02	3·38 1·03

* In hours and minutes.
† These figures are obtained by dividing the metres in line 7 by figures in line 1.
‡ Obtained by dividing metres in line 7 by figures in line 5.
§ Obtained by multiplying metres in line 9 by figures in line 1.
‖ Obtained by dividing the monthly advance (in Table 49) by the figures in line 1 of this Table. By comparing this line (12) with the average lengths of single holes (line 9), it will be seen that the average advance per attack is, in general, nearly equal to the average length of hole.

TABLE 52. (*Continued*).

1877.

		Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Rock-Drill Used.		5. McKean.			4. McKean.			7. McKean.					
1. Number of boring attacks........	....	97	83	73	114	102	88	67	104	81	101	34	35
2. Average time for drill-work proper in one attack*..............	....	4-4	3-47	3-50	3-27	4-19	5-12	4-2	3-58	4-33	4-1	2-8	3-22
3. Average time for blasting and clearing in one attack*.........	....	3-20	3-55	2-59	2-48	2-49	2-56	3-4	2-59	2-56	3-14	19-9	17-32
4. Total time for one boring attack*.	....	7-24	7-42	6-49	6-15	7-8	8-8	7-6	6-57	7-29	7-15	21-17	20-54
5. Number of holes drilled during month.........................	....	1563	1308	1231	1850	1742	1511	1072	1744	1410	1676	244	459
6. Average number of holes drilled per attack......................	....	16.11	15.76	16.86	16.22	17.07	17.17	16.00	16.77	17.48	16.59	7.17	13.11
7. Total length of all holes drilled during month..................	Feet. Metres.	5664.7 1696.1	4600.5 1402.2	4504.1 1372.8									
8. Average total length of holes in one attack†..................	Feet. Metres.	57.35 17.48	55.40 16.89	61.68 18.80									
9. Average length of single holes drilled during month‡..........	Feet. Metres.	3.57 1.09	3.51 1.07	3.64 1.11									
10. Sum of average single lengths of bore-holes for all attacks in the month§..........................	Feet. Metres.	356.29 105.73	291.33 88.81	265.72 81.03									
11. Number of machines sent to repair-shops......................	....	36	10	16	21	40	30	18	34	36	40	4	8
12. Average lineal advance of heading per attack‖.....................	Feet. Metres.	3.28 1.00	3.15 0.96	3.38 1.03	3.31 1.01	3.35 1.02	3.31 1.01	3.18 0.97	3.35 1.03	3.18 0.97	3.44 1.05	3.51 1.07	3.77 1.15

1878.

		Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Rock-Drill Used.		7. McKean.											
1. Number of boring attacks........	....	49	33	34	79	117	85	97	127	96	103	78	94
2. Average time for drill-work proper in one attack*..............	....	3-10	2-45	4-6	4-20	3-16	5-30	3-23	2-34	3-33	3-29	4-28	4-29
3. Average time for blasting and clearing in one attack*.........	....	12-5	17-37	17-12	4-54	3-50	3-26	2-59	3-12	3-33	3-46	3-32	3-27
4. Total time for one boring attack*.	....	15-15	20-22	21-18	9-16	7-16	8-56	6-22	5-46	7-6	7-15	8-0	7-56
5. Number of holes drilled during month.........................	....	656	322	447	1411	2080	1600	1752	2173	1631	1546	1245	1673
6. Average number of holes drilled per attack......................	....	13.40	9.76	13.15	17.86	17.77	18.62	18.06	17.11	17.00	15.00	16.00	17.79
7. Total length of all holes drilled during month..................	Feet. Metres.	2512.4 765.8	1024.7 312.3	1701.0 518.5	5344.1 1628.9	8707.0 2654.2	6793.5 2070.6	8047.4 2452.8	9624.4 2933.5	6367.8 1940.9	6761.9 2061.0	5452.8 1662.0	7621.5 2323.0
8. Average total length of holes in one attack†..................	Feet. Metres.	51.21 15.61	31.04 9.46	50.03 15.25	67.65 20.62	74.48 22.70	79.92 24.26	82.94 25.28	75.79 23.10	66.34 20.22	65.65 20.01	69.91 21.31	81.10 24.72
9. Average length of single holes drilled during month‡..........	Feet. Metres.	3.84 1.17	3.18 0.97	3.81 1.16	3.77 1.15	4.17 1.27	4.23 1.29	4.59 1.40	4.43 1.35	3.57 1.18	4.36 1.33	4.36 1.33	4.56 1.39
10. Sum of average single lengths of bore-holes for all attacks in the month§..........................	Feet. Metres.	118.16 57.33	104.94 32.01	129.54 39.44	297.83 90.85	487.89 148.50	359.55 109.65	455.23 135.80	562.61 171.45	342.72 113.28	449.08 136.99	340.08 103.74	428.64 130.66
11. Number of machines sent to repair-shops......................	....	10	4	8	16	47	67	50	51	39	41	27	57
12. Average lineal advance of heading per attack‖.....................	Feet. Metres.	3.57 1.09	3.54 1.08	3.64 1.11	3.54 1.08	4.00 1.22	4.03 1.23	4.33 1.32	4.43 1.35	3.94 1.20	3.97 1.21	4.16 1.27	4.26 1.30

* In hours nd minutes.
† These figures are obtained by dividing the metres in line 7 by figures in line 1.
‡ Obtained by dividing metres in line 7 by figures in line 5.
§ Obtained by multiplying metres in line 9 by figures in line 1.
‖ Obtained by dividing the monthly advance (in Table 49) by the figures in line 1 of this Table. By comparing this line (12) with the average lengths of single holes (line 9), it will be seen that the average advance per attack is, in general, nearly equal to the average length of hole.

TABLE 52. (*Continued*).

1879.

		Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
ROCK-DRILL USED.	McKean.												
1. Number of boring attacks	....	63	40	58	102	86	81	88	87	85	88	96	105
2. Average time for drill-work proper in one attack*	....	3-43	4-1	4-13	3-14	3-29	5-15	3-40	4-37	4-10	4-50	3-34	3-36
3. Average time for blasting and clearing in one attack*	....	5-12	9-36	5-8	3-17	3-27	3-40	4-23	3-48	4-7	3-26	3-47	3-28
4. Total time for one boring attack*	....	8-55	13-37	9-21	6-31	6-56	8-55	8-3	8-25	8-17	8-16	7-21	7-4
5. Number of holes drilled during month	....	1166	710	1090	1758	1574	1534	1654	1666	1473	1611	1814	1903
6. Average number of holes drilled per attack	....	18.51	17.75	18.79	17.23	18.30	18.94	18.79	19.15	17.33	18.31	18.89	18.12
7. Total length of all holes drilled during month	Feet. Metres.	5190.4 1581.0	3067.6 935.0	4727.8 1441.0	8114.3 2473.2	7060.5 2152.0	6716.6 2047.2	6975.2 2126.0	6604.4 2013.0	6020.4 1835.0	6414.1 1955.0	7142.9 2171.0	7821.7 2384.0
8. Average total length of holes in one attack†	Feet. Metres.	82.38 25.11	76.67 23.37	81.52 24.85	79.56 24.25	82.08 25.02	82.91 25.27	79.27 24.16	75.92 23.14	70.83 21.59	72.90 22.22	74.18 22.61	74.48 22.70
9. Average length of single holes drilled during month‡	Feet. Metres.	4.46 1.36	4.33 1.32	4.33 1.32	4.62 1.41	4.49 1.37	4.36 1.33	4.20 1.28	3.97 1.21	4.91 1.24	3.97 1.21	3.74 1.14	4.13 1.26
10. Sum of average single lengths of bore-holes for all attacks in the month§	Feet. Metres.	280.98 85.68	173.20 52.80	251.14 76.56	471.24 143.82	386.14 117.82	353.16 107.73	369.60 156.64	345.39 105.27	417.35 105.40	349.36 106.48	359.04 109.44	433.65 132.30
11. Number of machines sent to repair-shops	....	26	17	25	44	36	52	38	36	26	30	25	28
12. Average lineal advance of heading per attack‖	Feet. Metres.	4.17 1.27	3.57 1.18	3.84 1.17	4.36 1.33	4.17 1.27	4.00 1.22	3.84 1.17	3.58 1.09	3.61 1.10	3.67 1.12	3.51 1.07	16 ...8 d .113.

1880.

		Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
ROCK-DRILL USED.	McKean.												
1. Number of boring attacks	....	73	81			The two headings met on the 29th of February, 1880.							
2. Average time for drill-work proper in one attack*	....	4-20	4-13										
3. Average time for blasting and clearing in one attack*	....	4-2	4-3										
4. Total time for one boring attack*	....	8-31	8-16										
5. Number of holes drilled during month	....	1414	1635										
6. Average number of holes drilled per attack	....	19.37	20.18										
7. Total length of all holes drilled during month	Feet. Metres.	5751.3 1733	5941.7 1811										
8. Average total length of holes in one attack†	Feet. Metres.	78.77 24.01	73.36 22.36										
9. Average length of single holes drilled during month‡	Feet. Metres.	4.07 1.24	3.64 1.11										
10. Sum of average single lengths of bore-holes for all attacks in the month§	Feet. Metres.	297.11 90.52	294.84 89.91										
11. Number of machines sent to repair-shops	....	18	22										
12. Average lineal advance of heading per attack‖	Feet. Metres.	3.54 1.08	3.51 1.07										

* In hours and minutes.
† These figures are obtained by dividing the metres in line 7 by figures in line 1.
‡ Obtained by dividing metres in line 7 by figures in line 5.
§ Obtained by multiplying metres in line 9 by figures in line 1.
‖ Obtained by dividing the monthly advance (in Table 49) by the figures in line 1 of this Table. By comparing this line (12) with the average lengths of single holes (line 9), it will be seen that the average advance per attack is, in general, nearly equal to the average length of hole.

REPORT OF WORK AT THE U. S. WORKS, FLOOD ROCK, N. Y., FOR FISCAL YEARS ENDING JUNE 30.

(See p. 252.)

	1876.	1877.	1878.	1879.	1880.	1881.
Lineal feet of galleries driven	229	329	....	1306.78	4346.3	7312
Cubic yards of rock removed	1699.8	1772.2	....	5115.36	12941.02	18080
Loss of steel by abrasion (lbs.)	......	178	....	834	2531	4290
Number of feet of holes drilled	......	13311	....	55519	189809.5	269182
Number of holes blasted	......	3303	....	13389	43011	61595
Average depth of holes (ft.)	......	4.03	....	4.146	4.41	4.11
Number of times drills sharpened	......	1777	....	16682	57016	88272
Average drilling per cubic yard (ft.)	......	7.51	....	10.86	14.66	14.88
Exploders used	......	......	....	....	....	61595
Exploders, explosives used per cubic yard (lbs.)	......	2.08	....	2.16	2.48	2.59
Fuse used (ft.)	......	......	....	....	....	240269
Number feet holes drilled per day, 24 hours (3 shifts)	......	......	....	....	5367.5	....
Average depth drilled per drill, per 8 hr. shift (ft.)	......	......	....	....	35.36	31.72
Cost of drilling per lineal foot	......	......	....	.30	.25,9	.25,1
Cubic yards in place per lineal foot of gallery driven	7.46	5.38	....	3.91	2.95	2.47
Cubic yards per lineal foot of drill hole	......	.133	....	.092	.067	.067
Number of cars hoisted	......	......	....	....	....	32102
Material bought, wages paid drillers and helpers, miners, smiths and helpers, steam engineer and machinist. Machine work and drill, compressors, air-pipes, etc., engineer on hoisting engine, fireman and pumpman, overseer and sub-overseer, carpenters and laborers.	......	......	....	$3.59,6	$3.80,1	3.74,2
Explosives and laboratory, etc., repairs, material bought, explosives bought, wages paid blasters, carpenters and laborers	......	......	....	$1.45,6	$1.34,6	$1.43,6
Getting rock to shaft, mule stable, cars, tracks, etc, repairs, material bought, wages paid drillers and helpers, miners, smiths and helpers, overseers and sub-overseers, carpenters and laborers	......	......	....	$2.06,9	$1.58,6	$1.50,2
Hoisting and head frame, cages, etc., repairs, material bought, wages paid smiths and helpers, steam engineer and machinist, engineer on hoisting engine, fireman and pumpman, carpenters and laborers	......	......	....	$1.45,8	.26,2	.17,4
Dumping and cost of dumping scow, chute, etc., repairs, material bought, wages paid drillers and helpers, miners, smiths and helpers, fireman and pumpman, carpenters, laborers	......	......	....	.59,2	.71,5	.08,6
Pumping and cost of pump, etc., repairs, material bought, wages paid miners, smiths and helpers, steam engineer and machinists, engineer on hoisting engine, fireman and pumpman, carpenters and laborers	......	......	....	$1.20,5	.44,7	.35,7
Steam launch and repairs, material bought, wages paid steam engineer and machinists, steam launch carpenters, ass't engineer, sounder and boatman	......	......	....	.60,1	.10,9	....
Steamer A. A. Humphreys, including cost and repairs, material bought, wages paid smiths and helpers, steam engineer and machinists, fireman and pumpman, rent paid steamer A. A. H., wages paid carpenters	......	......	....	....	$1.09,6	.38,2
Boilers and condenser, setting, fitting, etc., repairs, material bought, wages paid drillers and helpers, smiths and helpers, fireman, pumpman, carpenters and laborers.	....	......	....	$2.581	.30,8	.19,2
Timbering in mine, material bought, wages paid miners, carpenters and laborers	......	......	....	.08,2	.09,6	.01,6
Crib building and repairs, material bought, wages paid smiths and helpers, carpenters and laborers	......	......	....	.35,5	.16,4	.25,2
Repair shop (machine), material and machinery bought, wages paid smiths and helpers, steam engineer and machinist, engineer hoisting engine, fireman and pumpman, carpenters and laborers.	......	......	....	.26,4	.04	.08,4
Sea wall, laborers	......	......	....	.36,9	.01	*
Row-boat, whale-boat, water-boat, boat-house, material bought, wages paid smiths and helpers, carpenters and laborers	......	......	...	.24	.05,4	.02,5
Superintendency, including cost of water, rent, etc., material bought, wages paid smiths and helpers, steam engineer and machinists, watchman, clerk, overseers and sub-overseers, carpenters, ass't engineer, sounder and boatmen	......	......	....	$2.48,6	.88,1	.62
Cost of increase of permanent plant	......	......	....	....	.76,5	.11,5
Ventilating mine (including cost of fan, engine, etc.)	......	......	....	....	....	....

* Included in erib building for 1881.

TABLE SHOWING ANALYSIS OF WORK AT FLOOD ROCK, N. Y.

(See p. 252.)

Detailed Report of work at U. S. Works, Flood Rock, New York, for Fiscal year ending June 30, 1881.	Amount drilled.	Shifts.	Average depth drilled per shift.	*Cost drillings per lineal ft.	Explosives used per cubic yard.	Average drilling per cubic yard.	Cubic yards removed.	No. of drills sharpened.	Loss of steel, abrasion and dressing.	Material bought.	Explosives bought.	Wages paid drillers and helpers.	Wages paid miners.	Wages paid blasters.	Wages paid smiths and helpers.	Wages paid steam engineer and machinists.	Wages paid engineer on hoisting engine.	Wages paid fireman and pumpman.	Wages paid Steamer A. A. Humphreys.	Wages paid watchman.	Wages paid, of material.	Wages paid overseer and sub-overseers.	Wages paid carpenters.	Wages paid asst. engineer, sounder, and boatmen.	Wages paid laborers.	Total cost.	Cost per cubic yard.
	Feet.	No.	Feet.	c	lbs.	Feet.	No.	No.	lbs.	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$
Mach. work and cost of drill, compressor, air-pipes, etc., repairs	369182	8485.375	31.72	25.1	2.59	14.88	180.80	88272	4290	15002.60		37548.73	63.92		3665.06	2497.18		2447.15				2777 68	236.66		3325.03	67665.01	3.71,2
Explosives and cost of laboratory, etc., repairs										73.65	23680.39			2128.89									19.25		62.48	25954.66	1.43,0
Getting rock to shaft and mine cars R. R., etc., repairs										3921.19		110.45	287.18		610.59	7.50						1007.43	1668.59		19553.87	27161.80	1.50,2
Hoisting and engine, etc., repairs										1862.47					17.52	30.00	742.04	364.41					30.25		92.51	3139.20	.17,4
Dumping and scow chute, etc., repairs										249.22					83.83								245.11		980.16	1558.32	.08 6
Pumping and pump, repairs										4261.15					5.09	260.70		1746.33					2.75		184.99	6461.01	.35,7
Steamer A. A. Humphreys, etc., repairs										2777.26					5.33	30.62			3862.21				175.71		49.25	6900.38	.38,2
Boilers and condensers, repairs										1187.00		22.72			32.80	682.14		159.47					47.40		1335.18	3460.80	.19,2
Timbering in mine										14.00		11.60	261.56										5.50			292.66	.01,6
Crib (at Hallet's Point), repairs										187.11													224.47		8405	495.63	.02,7
Crib and dyke (bet. Great and Little Mill Rocks), repairs										1639.86					83.18	10.00							443.61		1893.23	4060.88	.22,5
Ventilating mine (welding, cost of fan, engine, etc.), repairs										1097.48			191.69		28.80	14.87							289.80		362.05	2084.69	.11,5
Water-boat, whale-boat, row-boat, etc., repairs										7471.													382.77			457.48	.02,5
Repair-shop (including cost of lathe, etc.), repairs										1267.04					34.26	50.00							165.27			1511.57	.08,4
Superintendence (including cost of water, rent, etc.)										1182.09					238.99	1320.00				1185.65	1200.00	1920.00	1740.00	2459.33		11192.06	.02,2
Total																										$162421.15	$8.98

* Contributed by courtesy of Lieut. Geo. McC. Derby.

SHOWING PROGRESS ON FLOOD ROCK FOR FISCAL YEAR ENDING JUNE 30, 1881.

Lineal feet of galleries driven.	Cubic yards of rock removed.	Holes drilled.	Number of blasts.	Exploders used.	Fuse used.	Explosives (not dynamite) used.	Cars hoisted.
Feet.	No.	No.	No.	No.	Feet.	Lbs.	No.
7312	18080	65360	61595	61595	240360	46,866	33102

Total cost of material	$34,837.83
Total cost of explosives	23,680.39
Total cost of pay-roll	103,902.93
Total cost per cubic yard	8.98,3

TAB

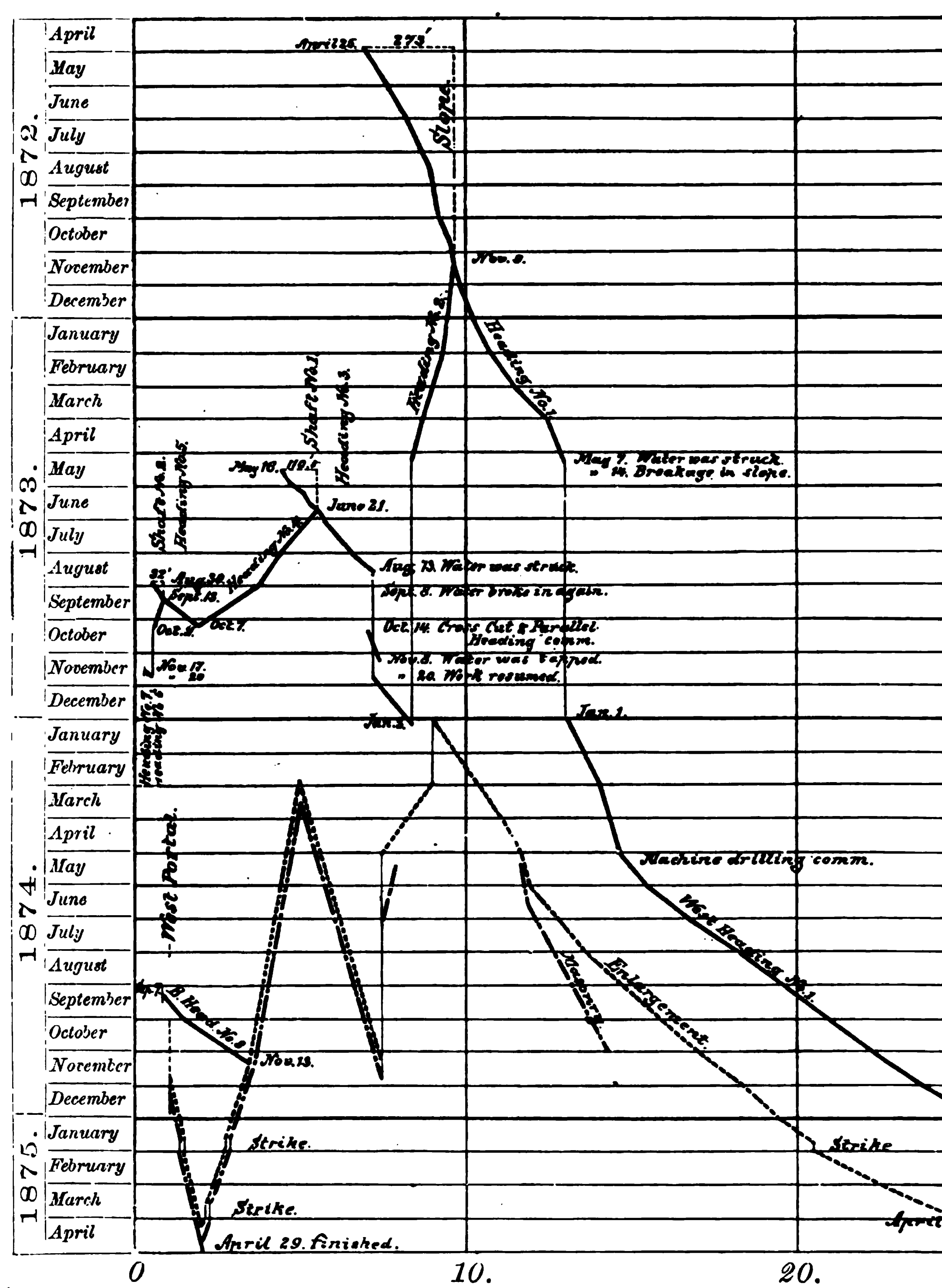
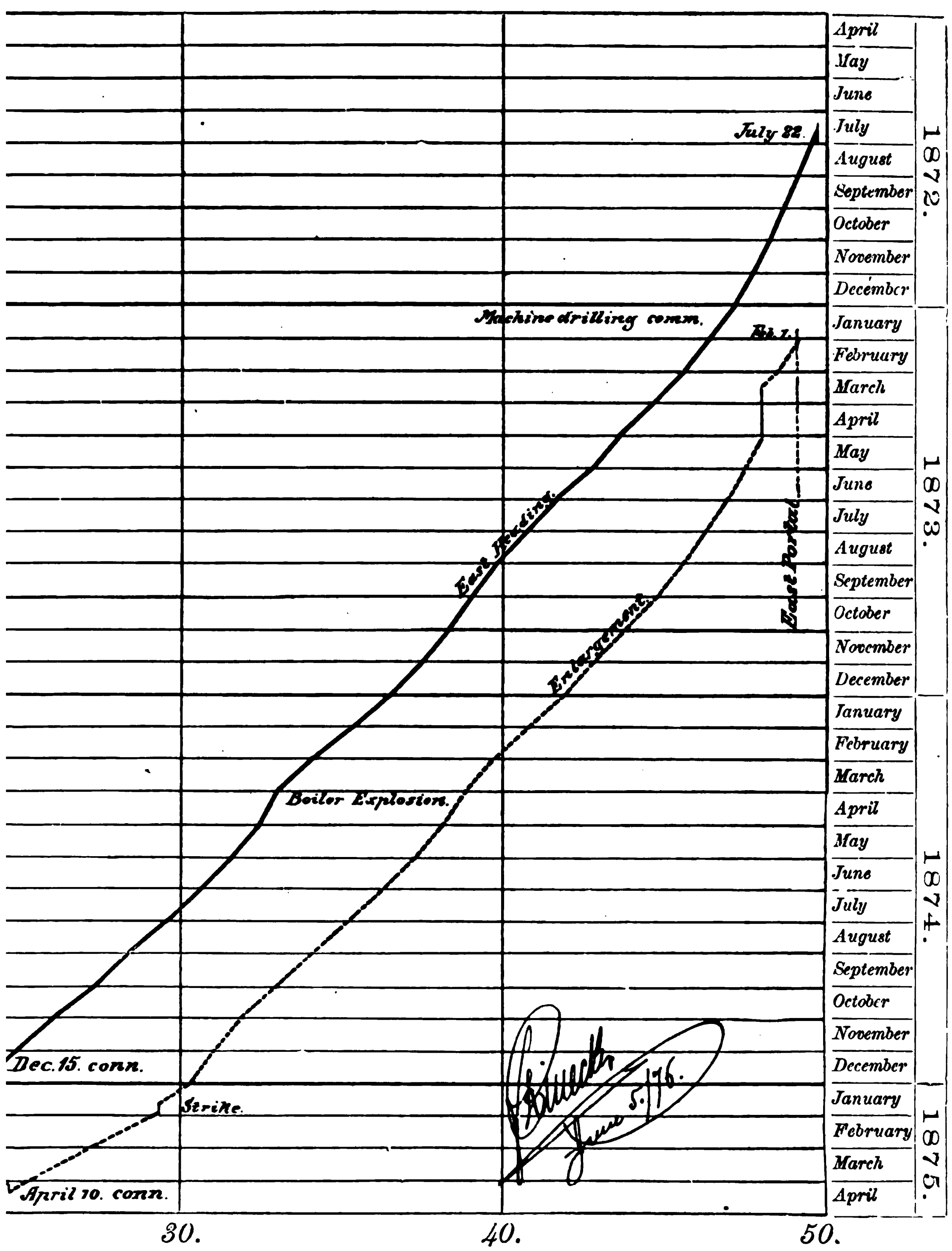


DIAGRAM OF PROGRESS

Scale, 500 feet = 1 inch for abscis

LE 53.



N MUSCONETCONG TUNNEL.

, and 5 months = 1 inch for ordinates.

TABLES

FOR THE

INTERCONVERSION OF ENGLISH AND METRIC UNITS.

By Prof. PERSIFOR FRAZER, Jr., A.M., Ph. D.

PRESENTED TO AMERICAN PHILOSOPHICAL SOCIETY, PHILADELPHIA, APRIL 5, 1878.

LINEAL UNITS.

INCHES.		CENTIMETRES.	FEET.		METRES.
0·3937079	=	1	1	=	0·3047945
1	=	2·539954	3·2809	=	1
0·787416	=	2	2	=	0·6095890
2	=	5·0799	6·5618	=	2
1·181124	=	3	3	=	0·9143835
3	=	7·6199	9·8427	=	3
1·574832	=	4	4	=	1·2191780
4	=	10·1598	13·1236	=	4
1·968539	=	5	5	=	1·5239724
5	=	12·6998	16·4045	=	5
2·362247	=	6	6	=	1·8287669
6	=	15·2397	19·6854	=	6
2·755955	=	7	7	=	2·1335614
7	=	17·7797	22·9663	=	7
3·149663	=	8	8	=	2·4383559
8	=	20·3196	26·2472	=	8
3·543371	=	9	9	=	2·7431504
9	=	22·8596	29·5281	=	9

YARDS.		METRES.	MILES.		KILOMETRES.
1	=	0·9143835	0·6214	=	1
1·093633	=	1	1	=	1·6093
2	=	1·8287669	1·2428	=	2
2·1873	=	2	2	=	3·2186
3	=	2·7431504	1·8641	=	3
3·2809	=	3	3	=	4·8279
4	=	3·6575340	2·4855	=	4
4·3745	=	4	4	=	6·4373
5	=	4·5719174	3·1069	=	5
5·4682	=	5	5	=	8·0466
6	=	5·4863009	3·7283	=	6
6·5618	=	6	6	=	9·6559
7	=	6·4006845	4·3497	=	7
7·6554	=	7	7	=	11·2652
8	=	7·315068	4·9711	=	8
8·7491	=	8	8	=	12·8745
9	=	8·2294514	5·5924	=	9
9·8427	=	9	9	=	14·4838

AREA.

SQ. INCH.		SQ. CENTIMETRE.	SQ. FEET.		SQ. METRE.
1	=	6·451367	1	=	0·09290
0·1550059	=	1	10·76393	=	1
SQ. YARD.		SQ. METRE.	SQ. YARDS.		ARE.
1	=	0·8360972	1	=	0·00836097
1·19603326	=	1	119·603326	=	1
ROOD.		ARE.	ACRE.		HECTARE.
1	=	10·11678	1	=	0·404671
0·098845	=	1	2·471143	=	1

THERMOMETER.			HEAT UNITS.		CALORIES.
FAHRENHEIT DEGREES.		CENTIGRADE DEGREES	1 LB. WATER 1° FAH.		1 KILOGRAM WATER 1° CEN.
1	=	0·55556	3·96832	=	1
1·8	=	1	1	=	0·251996

CAPACITY.

CUBIC INCHES.		CUBIC CENTIMETRES.	CUBIC FOOT.		CUBIC DECIMETRE (Litre).
1	=	16·38617589	1	=	28·315312
0·06102705152	=	1	0·03531658	=	1
CUBIC FEET.		CUBIC M. (Stere.).	CUBIC YARD.		CUBIC M. (Stere.).
1	=	0·028315	1	=	0·764513470
35·31658	=	1	1·3080215	=	1
MINIM.		CUB. CENT. M.	FLUID OZ.		CUB. CENT. M.
1	=	0·0616082	1	=	29·5719289
16·23158	=	1	0·033815	=	1
U. S. PINT. (WINE).		LITRE.	U. S. GAL. (231 C. I.).		LITRE.
1	=	0·47315083	1	=	3·7852067
2·1134908	=	1 a	0·264186	=	1
U. S. WINE BL. (31·5 Gals.).		LITRE.	GAL. (IMP.).		LITRE.
1	=	119·234017	1	=	4·54345728
0·00838686	=	1	0·2200967	=	1
U. S. BUSHEL. (2150·42 C. I.).		LITRE.	CORD.		STERE. (Cubic Metre).
1	=	35·2371556	1	=	3·624360
0·028379135	=	1	0·275911	=	1

SOLID PERCH (25 CUB. FT.).		CUBIC M. (Stere.).
1	=	0·7078828
1·412663	=	1

WEIGHT.

POUNDS TO FOOT.		KILOS. TO METRE.	POUNDS TO SQ. INCH.		KILOS TO SQ. CENTIMETRE.
1	=	1·48819	1	=	0·0703096
0·6719572	=	1	14·22283	=	1
GRAINS.		GRAMS.	POUNDS (AV.).		KILOGRAMS.
1	=	0·06479895086	1	=	0·453592653
15·43234874	=	1	2·2046212	=	1
OZ. (AV.).		GRAMS.	LBS. TROY.		KILOGRAMS.
1	=	28·349541	1	=	0·373241954
0·035274	=	1	2·679227	=	1

TONS.		TONNES (1000 kilos.).
Long (2240 lbs.)	=	1·0160475
Short (2000 lbs.)	=	0·9071853
Long, 0·9842059 } Short, 1·1023106 }	=	1

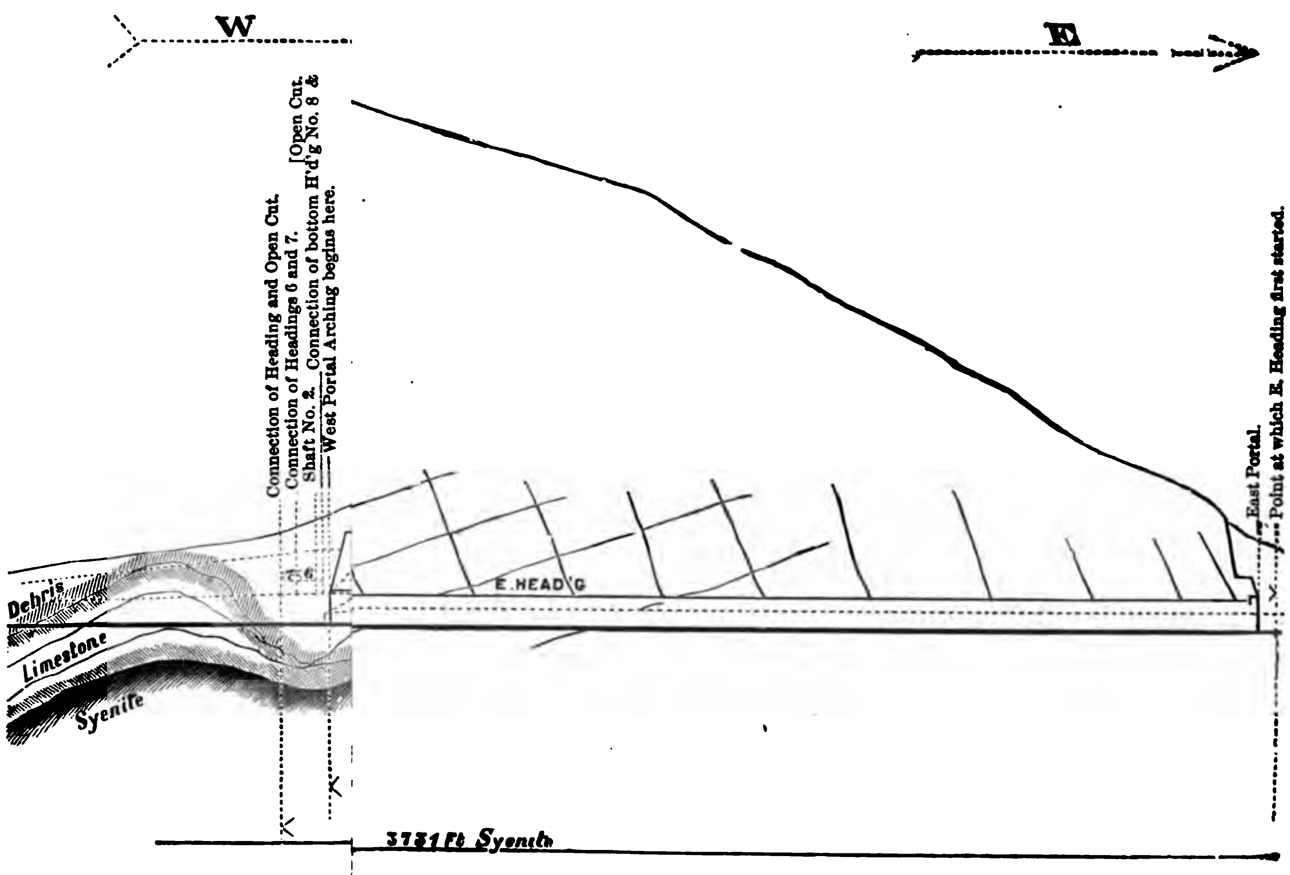
GRAINS PER U. S. GALLON.		MILLIGRAMS PER LITRE.	FOOT POUNDS.		KILOGRAMETRE.
1	=	17·1189987	1	=	0 138253
0·05841463	=	1	7·23314	=	1

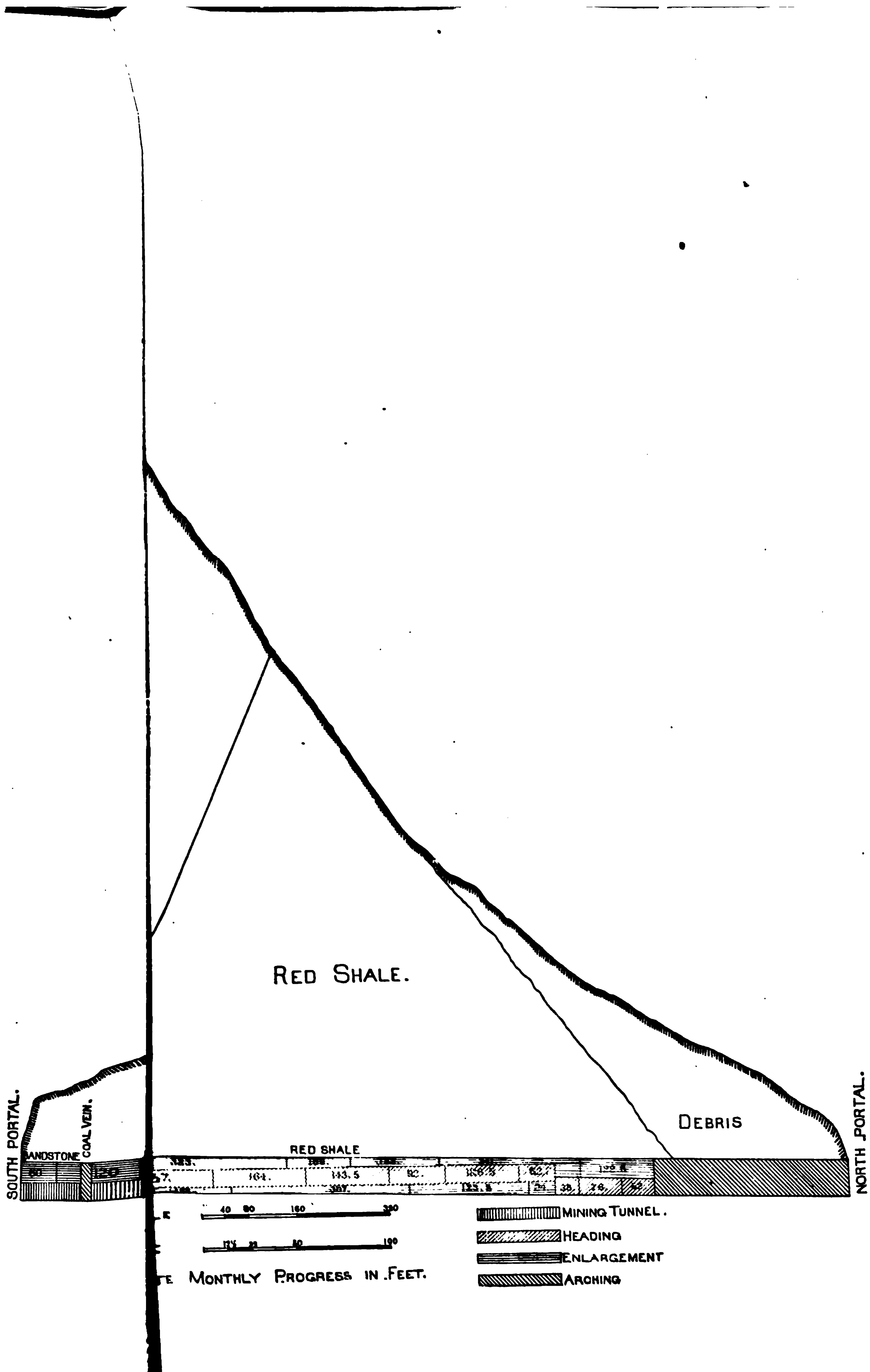
MISCELLANEOUS.

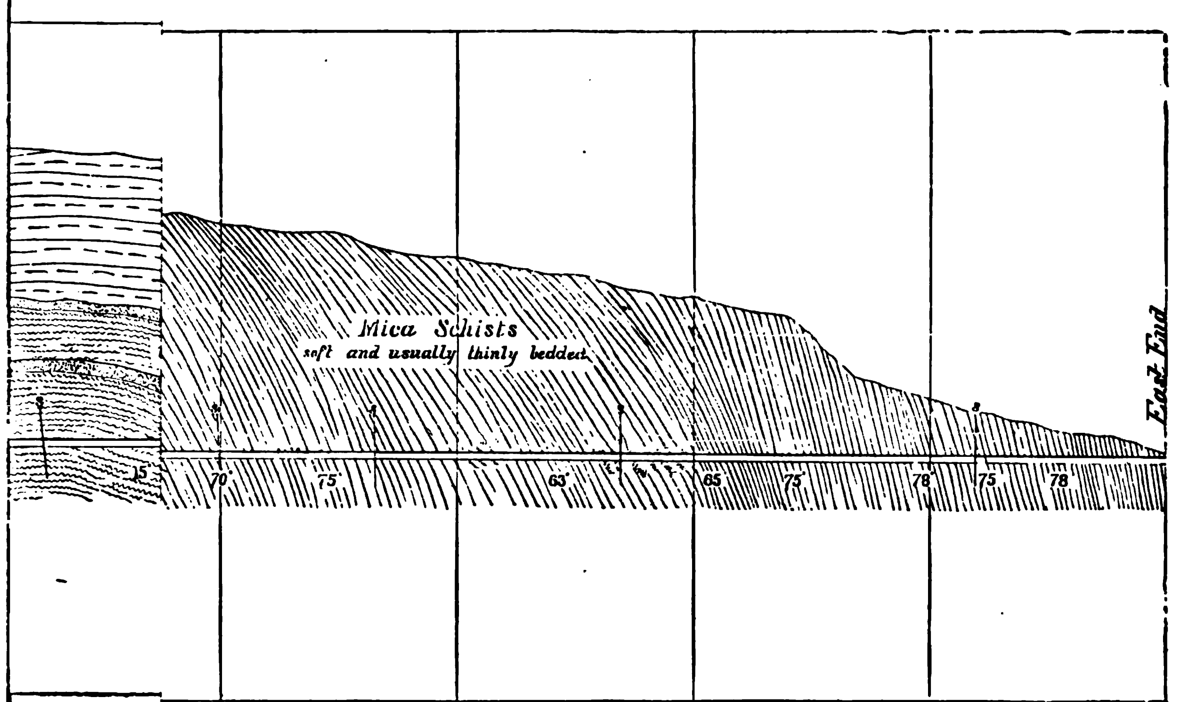
1 cubic inch water weighs = 252·7574 grains.
At. max. dens., Bar. 30 in. Air 62° F. (Barnard).
1 cubic foot water weighs = 62·3949696 lbs.

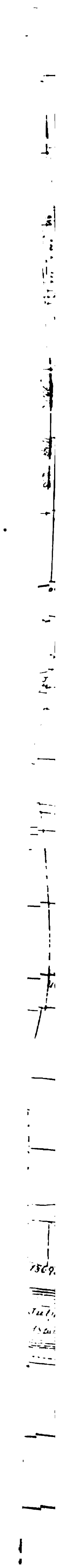
1 cwt. (112 lbs)	=	50·80238 kilos.
Quarter (28 lbs.)	=	12·700595 "
Drachm	=	1·77185 grams.

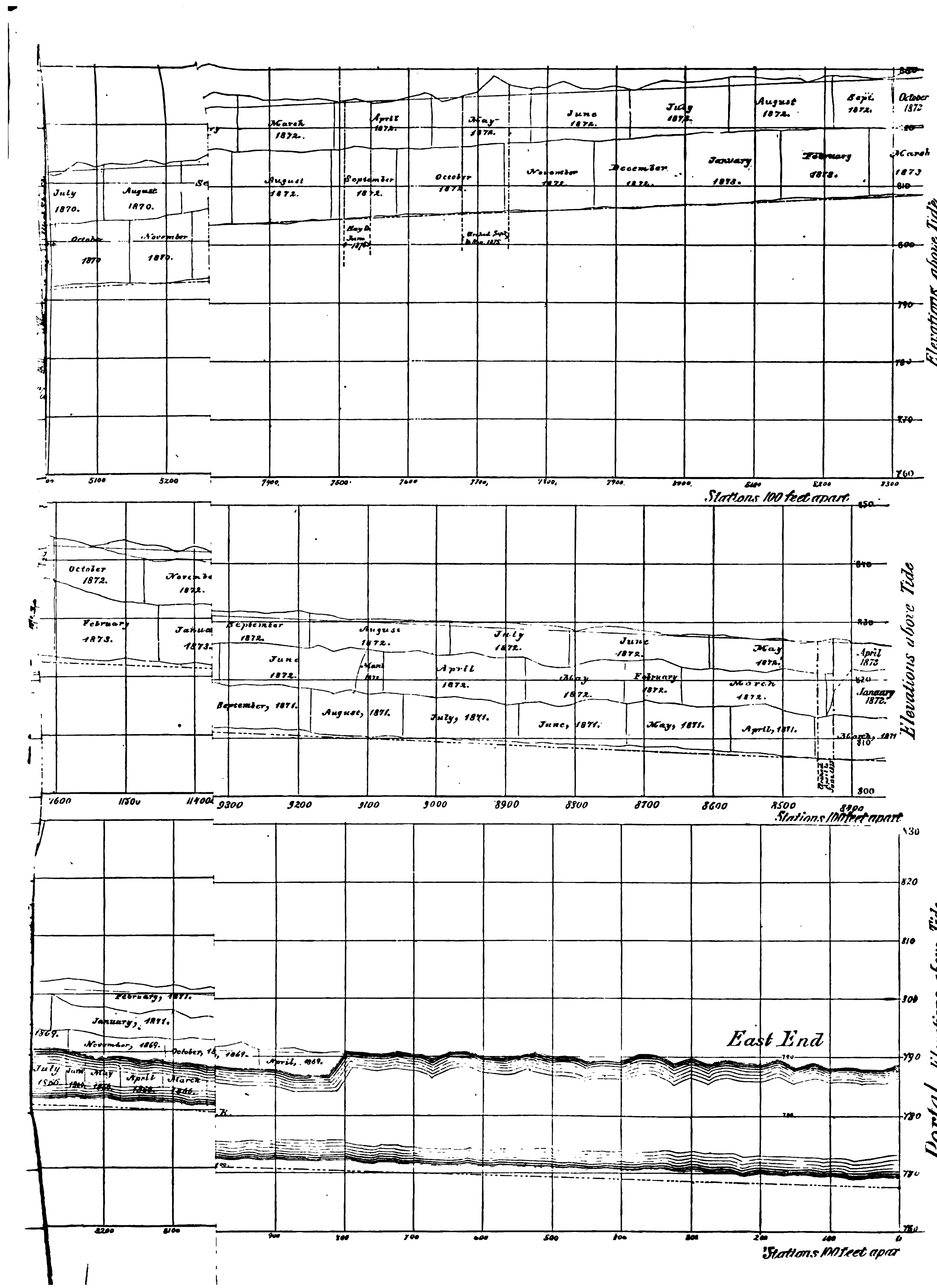
INDEX.


W
E
Connection of Heading and Open Cut.
Connection of Headings 6 and 7.
Shaft No. 2.
Connection of bottom H'd'g No. 8 & [Open Cut.
West Portal Arching begins here.
E. HEAD'G
Debris
Limestone
Syenite
East Portal.
Point at which E. Heading first started.


RED SHALE.
DEBRIS
SOUTH PORTAL.
COAL VEIN.
RED SHALE
NORTH PORTAL.
MONTHLY PROGRESS IN FEET.
MINING TUNNEL.
HEADING
ENLARGEMENT
ARCHING


Mica Schists
soft and usually thinly bedded
East End
15
70
75
63
65
75
78
75
78
21000
22000
23000
24000
25000





Elevations above Tide
Stations 100 feet apart
East End
Portal, Elevations above Tide
Stations 100 feet apart

Do NoT
USE